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Heavy Metal and Organic Contaminants in Arctic Marine Fishes

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HEAVY METAL AND ORGANIC CONTAMINANTS IN ARCTIC MARINE FISHES

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SUMMARY

The objective of this study was to provide preliminary baseline data on contaminants in arctic marine fishes with which to assess problems associated with increased industrialization in the Northwest Territories. Marine fish tissues, from seven locations (Arctic Bay, Resolute Bay, Pangnirtung, Frobisher Bay, Nauyuk (near Cambridge Bay), Tuktoyaktuk and Kugmallit Bay) were analysed for heavy metals and organochlorines. Polyaromatic hydrocarbons were determined in samples from Tuktoyaktuk and Resolute Bay while mixed function oxidase activity (MFO) was determined in fish liver from Tuktoyaktuk only. Heavy metals (Zn, Cu, Hg, Se and Cd) in individual fish tissues were present at generally lower concentrations than in northern freshwater or anadromous species except for cadmium. High cadmium levels were found in Arctic cod livers from Pangnirtung (0.91 µg/g wet wt) and in Fourhorn sculpin and Pacific herring livers from Tuktoyaktuk (0.56 and 0.86 µg/g, respectively). There was considerable variation in metal concentrations between individual fishes. No major geographic trends in levels of metals were evident.

Organochlorines (PCBs, DDT, chlordane, chlorobenzenes, hexachlorocyclohexanes (HCH) and toxaphene) were detected in all pooled fish muscle samples at low ng/g concentrations. These levels are about 10 to 100-fold lower than in marine fishes from the east coast of Canada or the Northwest Pacific. Toxaphene and HCH were found at higher concentrations than the other compounds in Arctic cod from Pangnirtung and Arctic Bay (3.5 - 46 ng/g wet wt) and in Pacific herring from Tuktoyaktuk (74 ng/g toxaphene and 12.5 ng/g total HCH). Few geographic differences in organochlorines were evident but there were great differences in residue levels between species from the same site (Tuktoyaktuk).

Polyaromatic hydrocarbons (PAHs) (naphthalene, phenanthrene, anthracene, fluoranthene, and pyrene) were detected in Arctic cod from Resolute Bay and in inconnu muscle from Tuktoyaktuk. Concentrations of all PAHs were low ranging from 0.3 ng/g for flouranthene to 8.1 ng/g for phenanthrene. PAH levels in inconnu from Tuktoyaktuk were similar to those in previous reports for fishes in this region but higher than levels reported in freshwater and marine fishes in some southern Canadian studies.

Mixed function oxidase enzyme activities in livers of fishes from Tuktoyaktuk harbour were generally higher than in published reports on other species from southern waters; however no firm conclusions could be drawn because of the lack of data on arctic species.

RÉSUMÉ

Le but de cette étude était d'obtenir sur les pollutants présents dans les poissons marins de l'Arctique des données de base préliminaires qui permettraient d'évaluer les problèmes associés à l'industrialisation accrue des Territoires du Nord-Ouest. On a dosé les métaux lourds et les produits organochlorés dans les tissus de poissons marins pêchés à sept endroits différents (Arctic Bay, Resolute Bay, Pangnirtung, Frobisher Bay, Nauyuk (près de Cambridge Bay), Tuktoyaktuk et Kugmallit Bay). On a dosé les hydrocarbures polyaromatiques dans des échantillons provenant de Tuktoyaktuk et Resolute Bay, et on a déterminé l'activité des oxydases à fonctions multiples (MFO) dans le foie de poissons provenant de Tuktoyaktuk seulement. À l'exception du cadmium, la concentration des métaux lourds (Zn, Cu, Hg, Se et Cd) était généralement plus faible dans les tissus de poissons individuels que dans les espèces d'eau douce et anadromes vivant dans le nord. On a trouvé des concentrations élevées de cadmium dans le foie de saidas provenant de Pangnirtung (0,91 $ug.g^{-1}$ en masse humide) et dans le foie de chaboisseaux à quatre cornes et de harengs pacifiques de Tuktoyaktuk (0,56 et 0,86 $ug.g^{-1}$ respectivement). Les concentrations de métaux variaient considérablement d'un poisson à l'autre et ne semblaient pas suivre une tendance géographique.

On a décelé de faibles concentrations (quelques $ng.g^{-1}$) de produits organochlorés (PCB, DDT, chlordane, chlorobenzènes, hexachlorocyclohexanes (HCH) et toxaphène) dans des échantillons de tissus musculaires préparés à partir de plusieurs poissons. Ces concentrations sont d'environ 10-100 fois plus faibles que celles mesurées dans les poissons marins pêchés au large de la côte est canadienne ou dans le secteur nord-ouest du Pacifique. La concentration de toxaphène et de HCH était plus élevée que celle des autres composés dans le saida de Pangnirtung et d'Arctic Bay (3,5 - 46 $ng.g^{-1}$ en masse humide) et dans le hareng pacifique de Tuktoyaktuk (74 $ng.g^{-1}$ de toxaphène et 12,5 $ng.g^{-1}$ de HCH total). Les concentrations de produits organochlorés variaient peu d'un endroit à un autre, mais on observait des différences importantes dans les concentrations de résidus chez différentes espèces pêchées au même endroit (Tuktoyaktuk).

On a décelé des hydrocarbures polyaromatiques (HPA) (naphtalène phénanthrène, anthracène fluoranthène et pyrène) dans les saidas de Resolute Bay et dans les muscles de Stenodus leucichthys pêchés à Tuktoyaktuk. La concentration de tous les HPA était faible, allant de 0,3 $ng.g^{-1}$ pour le fluoranthène à 8,1 $ng.g^{-1}$ pour la phénanthrène. Les concentrations de HPA dans Stenodus leucichthys de Tuktoyaktuk étaient semblables à celles signalées dans des rapports précédents pour les poissons de cette région, mais elles étaient plus élevées que celles signalées pour les poissons d'eaux douces et les poissons marins dans certaines études effectuées dans des régions du sud du Canada.

L'activité des oxydases à fonctions multiples dans le foie de poissons pêchés dans le port de Tuktoyaktuk était généralement plus élevée que celle signalée dans des rapports portant sur des espèces vivant plus au sud; toutefois, vu l'absence de données sur les espèces arctiques, il a été impossible de tirer des conclusions sûres.

INTRODUCTION

The presence of heavy metal and organic contaminants in biota from arctic freshwater and marine environments has been known for about 15 years. Most investigations have focussed on levels of these contaminants in marine mammal tissues and in commercial freshwater fishes and have not included marine fishes.

The major objective of this project was to survey heavy metal and organic contaminants in a limited number of marine fishes from a wide geographic area of the Canadian arctic. The intention was to provide preliminary baseline data for a large number of individual contaminants with which to assess future problems associated with industrial development in the arctic and to address contamination problems already identified by a few northern communities. An additional specific objective, which was formulated once sampling had begun, was to provide data on contaminants in the diets of native peoples who consume marine fish, although marine species, other than anadromous Arctic char, (Salvelinus Alpinus) represent only 0.5 to 2.0% of the fish consumed by coastal communities in the N.W.T. (Wong, 1985).

Heavy metal and organic contaminants are present in Arctic marine waters as the result of oceanic transport, riverine input and atmospheric deposition. Riverine and oceanic inputs are the major transport pathways for trace elements, such as Cd, Al, Mn and Pb, into the Arctic Ocean although atmospheric deposition may also contribute a significant fraction of Cd and Pb (Rahn, 1982; Mart, 1983). The extent to which the metal inputs are of anthropogenic origin is difficult to assess. In the case of Hg, atmospheric deposition on the Greenland icecap has remained similar over the past 200 years indicating that the major contribution is from natural sources (Ottar, 1982). Monitoring of metals in marine biota was initiated in northern Baffin Island and Greenland as the result of development of base-metal mining (Bohn and Fallis, 1978; Fallis, 1982). High levels of Hg in liver of Ringed seals (10-30 µg/g) and Bearded Seals (143 µg/g) from Holman Island were first reported in 1975 (Smith and Armstrong, 1975; 1978). High levels of Cd and Zn have also been reported in Ringed seals (Wagemann and Muir, 1984) and Narwhals from Northern Baffin Island (Wagemann et al., 1983). Recent studies by Macdonald and Sprague (1985) suggest that high levels of heavy metals in marine mammals are the result of normal food chain accumulation from fishes and crustaceans. There have been few investigations of the levels of heavy

metal contaminants at lower trophic levels in the arctic marine food chain. A substantial data base is available from DFO, Fish Inspection (Winnipeg), on levels of heavy metals (mainly Hg) and organochlorines but it is limited to commercial freshwater and anadromous species (mainly Arctic char).

The relative importance of riverine, oceanic and atmospheric contributions of organic contaminants to arctic marine waters is less well understood than for metals. Localized inputs of petroleum hydrocarbons from oil seeps are well known in the Mackenzie River, Alaskan north slope and Baffin Island (Wilson et al., 1973). Releases of oil and refined products are also possible from hydrocarbon transport and exploration. Polyaromatic hydrocarbons (PAHs) have been measured in arctic air at Barrow (Alaska) (Daisey et al., 1981) and at Bear Island north of Norway (Oehme and Mano, 1984) suggesting that combustion sources in the mid-latitudes could contribute contaminants to arctic waters. PAHs are of great interest from a biological point of view because of the carcinogenicity of some isomers. Apart from surveys by Wong et al. (1976) in the southern Beaufort Sea, relatively little monitoring data on PAHs in arctic biota has been published (Clark and Finley, 1982). Mixed-function oxidases have been used successfully to detect effects of oil pollution on fish (Payne, 1984) but more information is needed on the normal levels and variation of these enzymes in arctic fishes before these tests can be used to assess effects of PAH or other enzyme inducers.

Organochlorine (PCBs and chlorinated pesticides) inputs into the arctic marine environment are, unlike PAHs and heavy metals, clearly of anthropogenic origin. Past uses of these compounds in North America and Europe, combined with continued use of chlordane, hexachlorocyclohexanes and DDT in Asia, Central America and possibly Eastern Europe appear to be responsible for measurable concentrations in arctic air (Oehme and Mano, 1984; Hoff and Chan, 1986) and in deposition in the Hudson Bay drainage area (Rapaport et al., 1985; Rapaport and Eisenreich, 1986). A territorial-wide survey of organochlorines in polar bear fat and livers suggested inputs of organochlorines, especially chlordane, increased during the period 1969 to 1984 (Norstrom et al., 1985). The presence of PCBs and DDT isomers in arctic seal blubber samples was first reported in the late 1960's (Holden, 1969). Subsequent investigations reported relatively low (0.5 - 5 µg/g) concentrations of organochlorines in Ringed seals and Beluga whales from the Western arctic (Addison and Brodie, 1973; Addison and Smith, 1974) and

Greenland (Clausen et al., 1974; Johansen et al., 1980). However, there have been no surveys of organochlorines in marine fishes such as Arctic cod which are an important component of the diet of marine mammals in the Eastern and Central arctic.

METHODS

Sampling. Sampling sites were selected to provide wide geographic coverage of the arctic archipelago and for convenience of sample transport by air to Winnipeg. Location of the sampling sites is given in Table 1 and on the map in Figure 1. Fish samples were collected by DFO personnel (except for Arctic Bay where they were collected for the University of Guelph by G. Williams) between August 1984 and April 1985. All fishes were captured with gill nets except Arctic cod from Pangnirtung which were obtained (intact) from a Beluga stomach. Samples were shipped to Winnipeg with dry ice in styrofoam containers. Upon receipt fishes were dissected and tissues prepared for analysis of metals or organics. At Tuktoyaktuk, fish livers prepared for enzyme assays were dissected in the field and then frozen before shipping. All tissues were stored at -60°C until analysis. Otoliths of the fish were removed for age determination.

Metal analyses. Heavy metal analyses were performed on the tissues of individual fish (liver, kidney, gonads and muscle) subject to availability where fish were small. Except for the largest fishes the available quantity of liver and kidney was too small to allow more than one element to be determined. Methods of analysis are described in detail by Wagemann et al. (1983). In brief, 0.5 - 1.0 g of dried tissue was digested with nitric and perchloric acids. Analysis for Cu, Cd and Zn was by flame atomic absorption. Blanks and NBS (National Bureau of Standards, Washington, D.C.) bovine liver standards were also carried through the entire procedure. For Se, dried tissues (0.2 g) were digested with nitric and perchloric acids, followed by addition of HCl and analysis of the hydride (generated by reduction with sodium borohydride) by flameless atomic absorption. For Hg, dried tissues were digested with a mixture of sulfuric and nitric acid (4:1) followed by addition of potassium permanganate. After standing overnight the Hg was determined by cold-vapour atomic absorption.

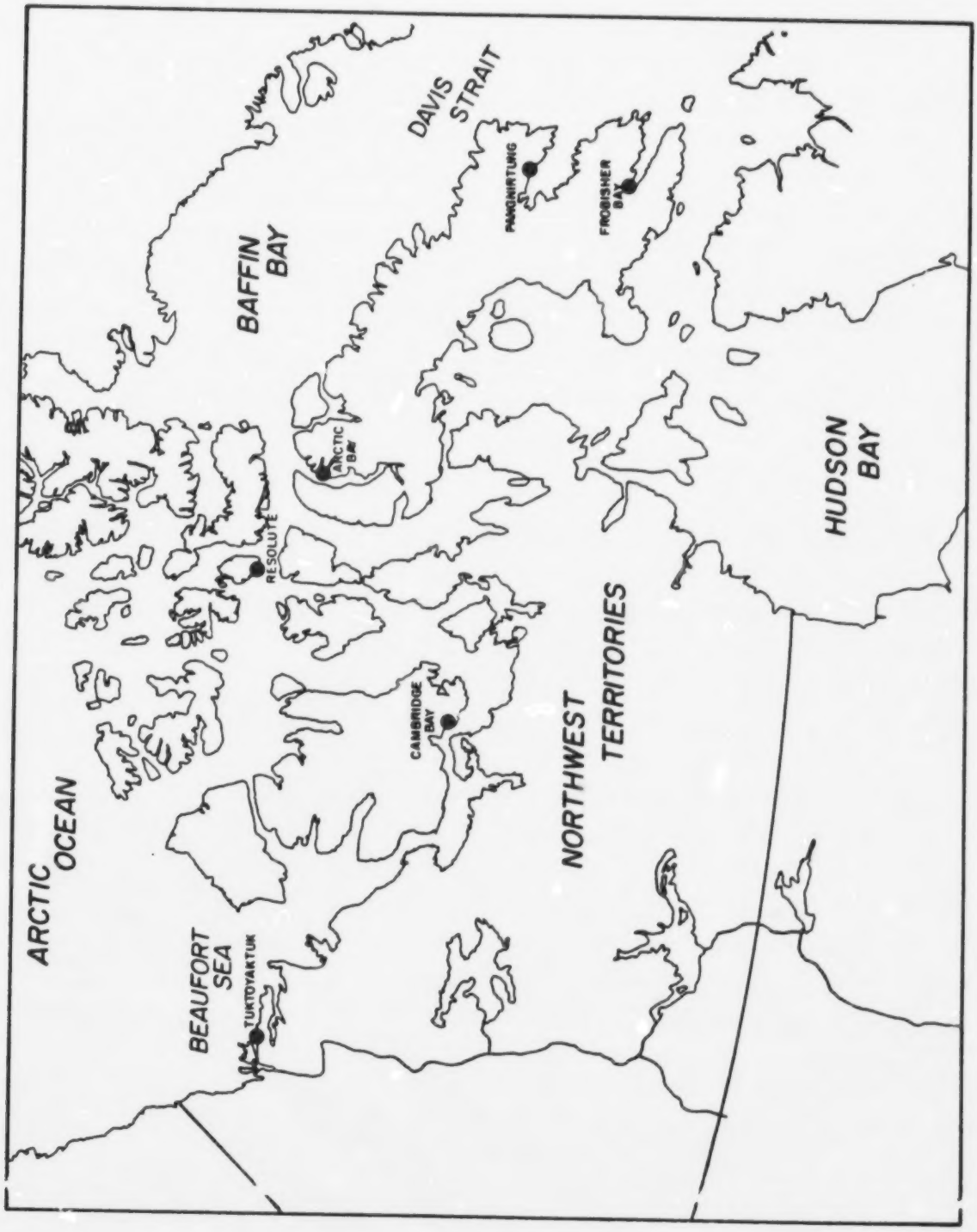
Table 1. Listing of arctic marine fishes analysed for heavy metals, organochlorines, polyaromatic hydrocarbons, and mixed-function oxidase enzymes.

Location	No. Specimens	Species	Pool #	Field No.
Arctic Bay	39	Arctic cod (*Boreogadus saida*)	1	1 - 27
			2	18 - 38
			3	47
Resolute	19	Arctic cod (*Boreogadus saida*)	1	1 - 14,78 - 83
	2	Fish Doctor (*Gymnelis viridis*)		2,3
	1	Fourhorn sculpin (*Myoxocephalus scorpioides*)	2	65,67
Pangnirtung	10[1]	Arctic cod (*Boreogadus saida*)	1	1,4,6,9,12, 16-18,20,22
Kugmallit Bay	16	Arctic cod (*Boreogadus saida*)	1	1 - 16
Tuktoyaktuk	2	Broad Whitefish (*Coregonus nasus*)	1	9,37
	8	Broad Whitefish (*Coregonus nasus*)	MFO	9,11,32,37,40, 43,60,61B
	5	Lake Whitefish (*Coregonus clupeaformis*)	MFO	10,17,18,19,33
	1	Burbot (*Lota lota*)	MFO	35
	3	Arctic Sculpin (*Myoxocephalus scorpioides*)	2	16,65,67
	2	Pacific Herring (*Clupea harengus pallasii*)	3	26, 27
	7	Starry flounder (*Platichthys stellatus*)	4	44,70-74,77
	2	Starry flounder (*Platichthys stellatus*)	MFO	20,21
	1	Arctic flounder (*Liopsetta glacialis*	MFO	15
	1	Inconnu (*Stenodus leucichthys*)	5	30
	4	Inconnu (*Stenodus leucichthys*)	MFO	30,31,36,38
Cambridge Bay (Nauyuk)	10	Greenland cod (*Gadus ogac*)	1	1,2,4-11
	1	Greenland cod (*Gadus ogac*)	2	3
Frobisher Bay (Soper Lake)	1[2]	Greenland cod (*Gadus ogac*)	1	1
	1		2	2

[1] Arctic cod from stomach content of Beluga landed at Pangnirtung.

[2] Frobisher samples were individual whole fish from an estuarine area near North Bay south of Frobisher, N.W.T.

Figure 1. Location of sampling sites for marine fishes.



Enzyme assays. Three different mixed-function oxidase (MFO) activities were measured in selected liver samples from the fish from Tuktoyaktuk Harbour. The three activities were: benz(a)pyrene hydroxylase, measured using modifications of the methods of Depierre *et al.* (1975) and Van Cantfort *et al.* (1977); ethoxyresorufin O-deethylase, measured using modifications of the methods of Burke and Mayer (1974) and Prough *et al.* (1978); and O-demethylase (p-nitroanisole substrate) using modifications of methods of Kato and Gillette (1965), Schoene *et al.* (1972), and Forlin and Lidman (1979). Protein in microsomal suspensions was measured by the method of Lowry *et al.* (1951) as modified by Markwell *et al.* (1981). In brief, liver tissue was homogenized with 0.02M HEPES/0.15M KCl buffer (pH 7.5) and centrifuged at low speed to remove insoluble matter, and then the supernatant was centrifuged at high speed to recover the microsomal pellet. The pellet was resuspended in buffer and assayed for enzymatic activity and for protein content.

Organic analyses. Chlorinated hydrocarbons were analysed mainly in pooled samples of fish muscle from the same fishes analysed for metals (Table 1). Pooling was found to be necessary because of the small size of most of the fish (particularly Arctic cod) and the low levels of contaminants. Samples were pooled by homogenizing muscle with dry ice in a blender. PAHs were analysed in fish from Tuktoyaktuk and Resolute Bay collected at the same sites as the specimens analysed for the other contaminants. Samples for PAH analysis were homogenized at room temperature in a blender and extracted immediately.

(1) **Extraction.** For extraction of polyaromatic hydrocarbons (PAH), 10 g homogenized fish muscle was mixed with anhydrous sodium sulfate and extracted in a Soxhlet apparatus with dichloromethane (DCM) (16 hrs). For organochlorines 10-50 g of homogenized tissue was extracted by the same technique using hexane as the solvent. DCM and hexane extracts were concentrated to small volume on a rotary evaporator and taken up in hexane: DCM (1:1) for gel permeation chromatography (GPC).

(2) **Separation of lipids.** Biogenic lipids were separated from organochlorines by GPC followed by Florisil chromatography (Norstrom and Won, 1985). The Florisil column was eluted with hexane (Fraction 1) to recover PCBs, hexane:DCM (85:15) (Fraction 2) to recover moderately polar organochlorines and hexane:DCM (1:1) to elute polar organochlorines such as heptachlor

epoxide. PAHs were also separated from lipids using GPC and the eluate was chromatographed on a column consisting of activated silica gel (11g, 100-200 mesh) topped with alumina (1g). The sample extract was applied to the column in hexane and alkanes eluated with 25 mL hexane. PAHs were eluted from the column with 25 mL Hexane: DCM (1:1).

(3) **GC and GC-MS analysis.** Gas chromatography of organochlorines was carried out on a Varian 6000 and on a Hewlett Packard 5890 both equipped with ^{63}Ni electron-capture detectors. The Varian instrument was fitted with a 30 m x 0.25 mm fused-silica DB-5 capillary column and the HP instrument with a 60 m column of the same type. Carrier gases were nitrogen (Varian) at 10 psi and helium (HP) at 25 psi. For separation of organochlorines the Varian GC was temperature programmed from 70° (2 min hold) to 250°C at 10°C/min. The HP instrument was programmed from 100°C (0.7 min hold) to 150°C at 10°C/min and from 150 to 280 at 3°C/min. Under these conditions decachlorobiphenyl had a retention time of 33.3 min (Varian) and 52.2 min (HP). Detector and injector temperatures were 300°C and 250° C, respectively. Linearity of response was monitored each day by injecting standard mixtures ranging in concentration from 5 to 50 pg/µL of each compound. Detector output was integrated on a Spectra-Physics 4270 (Varian) and on a HP 3990.

PCBs were quantitated as individual congenors using well-characterized standards obtained from the National Research Council of Canada (Halifax). Structures of the individual PCB isomers, which are referred to in this report by their IUPAC numbers, are listed in Appendix Table 13A. Where standards were not available eg. PCB 70 or where gas chromatographic peaks consisted of two or more compounds eg. PCB's 70/76, 95/66, 56/60/84/89, an average response factor was calculated from the proportion of the PCB isomer in the total ion chromatogram of an Aroclor 1254 standard. Chlordane, DDT, HCH and HCB isomers were quantitated using authentic standards (verified by GC-MS). A nonachlor isomer, U3, was quantitated using t-nonachlor. Toxaphene peaks were quantitated by summing areas of six peaks in Florisil Fraction 2, identified as toxaphene-related by GC-MS and multiplying by a response factor based on the area of the six peaks in a toxaphene standard.

GC-MS confirmation of organochlorines was carried out on a Hewlett Packard 5987 system using selected ion monitoring (SIM) on 60m or 30m DB-5 capillary columns. SIM was performed in the electron-impact mode at 70 eV.

Characteristic ions for tri- to octa-chloro PCBs, chlordane-related compounds, HCH, chlorobenzenes, toxaphene and DDT isomers were searched in selected retention time windows. Tri- and tetra- chloro isomers in two Arctic cod samples (Resolute and Arctic Bay) were quantitated by SIM using average response factors calculated for tetra, penta and hexa PCB isomers.

PAH analysis was carried out by high pressure liquid chromatography (HPLC) on a Varian 4500 instrument using a reverse phase column (Ultrasphere ODS, 25 cm x 4.6 mm i.d.; 5 µm particle size). A solvent gradient of acetonitrile-water (65:35) (10 min hold) to 85:15 was used. Solvent flow rate was 1.5 mL/min. PAHs were monitored with a UV detector at 254 nm and with a fluorescence detector (Kratos FS 970) set at excitation and emission wavelengths of 280 nm and 289 nm, respectively. GC-MS analysis for selected priority pollutant PAHs was carried out on a Hewlett-Packard 5988 instrument on a 12 m x 0.2 mm DB-1 column using SIM at 70 eV. The GC oven was temperature programmed from 50°C (2 min hold) to 270°C at 10°C/min (5 min hold). Under these conditions benz(a)pyrene had a retention time of 25.0 min. Three characteristic ions of each PAH compound (Table 14A) were monitored at selected retention time windows and results were compared with an external PAH standard run under the same conditions.

(4) **Blank analyses.** Procedural blanks were prepared for both PAH and organochlorine determinations to check contamination from solvents, glassware, sodium sulfate and soxhlet extraction thimbles. In addition, analyses of (*Esox lucius*) pike (Freshwater Fish Marketing Corp., Winnipeg) known to be low in organochlorine residues were carried out; however, levels of organochlorines were higher than in most Arctic marine samples. Final blanks for organochlorines were free of interfering peaks except for phthalate esters observed mainly in Fraction 1.

Initial work on extraction of PAHs included use of dry-ice to homogenize tissue samples. Blank determinations revealed interferences, presumably PAHs from the CO_2 used to make the dry-ice and the work was repeated omitting this step. Final PAH blanks were free of UV absorbing and fluorescent peaks.

(5) **Recovery studies.** Pike muscle was fortified with 3, 15 and 60 ng/g of p, p'-DDE and with lower concentrations of other organochlorines. Fortification levels for PAHs were 50 ng/g. All fortifications were carried out in triplicate beginning with the extraction step and using 10 g fish muscle samples.

RESULTS

Metals. Mean concentrations of metals in fish tissues for various species and geographic locations are given in Tables 2 to 8. The individual results from which the means were calculated are given in Tables 1A to 8A of the Appendix.

Zn and Cu concentrations in tissues of Arctic cod varied widely with location and amongst individual fish (Tables 2,3,5 and 7). Zn concentrations in cod muscle from Pangnirtung (22 µg/g) were significantly higher (P=0.05) than those in cod from Arctic Bay or Kugmallit Bay. The higher levels in the Pangnirtung samples may reflect the greater age of these fishes(11-12 years) compared to the other Arctic cod analysed (2-6 years). Wide differences in Zn concentrations were also seen in four different species from Tuktoyaktuk harbour (Table 6). Cu concentrations in cod muscle showed much less variation with location (Table 2) or species (Table 6) than Zn with mean levels in the 0.4 to 1.4 µg/g range.

Hg was present at low (0.05 µg/g or less) concentrations in almost all species and tissues examined (Table 2 - 8). Levels of Hg in Fourhorn sculpin liver and muscle from Tuktoyaktuk harbour (Table 6) were 4 to 6-fold higher than in Arctic cod (Table 2 and 3) and sculpin samples from Resolute Bay (Table 8). The Tuktoyaktuk sculpins were 8 and 13 years old, far older than either herring or flounder. The Hg concentration in muscle of some species of freshwater fishes is known to be dependent on age (Scott, 1974; Scott and Armstrong, 1972). The limited number of data points did not permit the testing of this relationship although this would have been of interest for marine fishes in view of their importance in the food chain leading to marine mammals.

Cd concentrations were highest in liver tissues of Arctic cod (Table 3), Fourhorn sculpin and Pacific herring (Table 6) ranging from 0.56 to 0.91 µg/g. Cd was undetectable in Greenland cod muscle (<0.05 - <0.07 µg/g) (Table 8). Se concentrations were quite uniform in muscle of all species examined ranging from 0.3 to 0.5 µg/g (Table 2, 6, 7, 8). Highest levels of Se were found in kidney and liver of Pacific herring (2.95 and 3.27 µg/g, respectively).

Table 2. Average metal concentrations ± SD, and range( ) in muscle of Arctic Cod from various locations in the arctic (µg/g, wet wt)[1]

n[2]	Age	Cu	Cd	Zn	Hg	Se
Arctic Bay						
8	(4-6)	0.94±0.69 (0.07-1.74)	<0.07	11.26±3.63 (7.20-16.97)	0.02±.004 (0.02-0.03)	0.50±0.19 (0.21-0.81)
Kugmallit Bay						
6	(2-3)	1.06±0.67 (0.12-1.70)	<0.05	7.89±4.75 (1.44-12.76)	0.02±0.01 (0.01-0.02)	0.42±0.06 (0.33-0.51)
Cambridge Bay						
1	--	0.60	<0.05	7.26	0.02	0.33
Resolute Bay						
2	(2-3)	1.43	<0.05	10.71	0.04±0.02 (0.02-0.05)	0.43±0.01 (0.42-0.43)
Pangnirtung						
6	(11-12)	0.92±0.55 (0.05-1.53)	<0.06	21.96±5.71 (14.16-28.16)	0.03±0.01 (0.02-0.05)	0.35±0.10 (0.20-0.46)

[1] Individual data for this table are given in Table 2A, Appendix.
[2] n = Number of samples.

Table 3. Average metal concentrations ± SD, and range( ) in liver of Arctic Cod from various locations in the arctic (µg/g, wet wt)[1]

n[2]	Age	Cu	Cd	Zn	Hg	Se
Arctic Bay						
8	(4-6)	--[3]	--	--	--	0.85±0.14 (0.62-0.98)
Kugmallit Bay						
6	(2-3)	--	--	--	--	0.48±0.22 (0.24-0.78)
Resolute Bay						
3	(2-3)	--	--	--	--	0.58±0.40 (0.30-0.86)
Pangnirtung						
6	(11-12)	<2.50	0.91±0.47 (0.50-1.40)	24.86±2.87 (20.37-28.16)	0.01±0.01 (0.01-0.03)	0.62±0.20 (0.30-0.85)

1 Individual data for this table are given in Table 1A, Appendix.
2 n = Number of samples.
3 dashes indicate too little sample available for analysis.

Table 4. Average metal concentrations ± SD, and range( ) in kidney of Arctic cod from various locations in the arctic (µg/g, wet wt)[1].

n[2]	Age	Cu	Cd	Zn	Hg	Se
Arctic Bay						
6	(4-6)	--[3]	--	--	--	0.91±0.32 (0.38-1.28)
1	5	--	--	--	--	0.05
Kugmallit Bay						
4	(3-3)	--	--	--	--	0.58±0.26 (0.32-0.85)
Cambridge Bay						
1	--	--	--	--	--	1.20
Pangnirtung						
6	(11-12)	--	--	--	0.05	0.81±0.19 (0.56-1.15)

[1] Individual data for this table are given in Table 3A, Appendix.
[2] n = Number of samples.
[3] dashes indicate too little sample available for analysis.

Table 5. Average metal concentrations ± SD, and range( ) in gonads of Arctic cod from various locations in the arctic (µg/g, wet wt)[1].

n[2]	Age	Cu	Cd	Zn	Hg	Se
Arctic Bay						
3	(4-5)	-- [3]	--	--	--	<0.70 (<0.70)
Cambridge Bay						
3	--	--	--	--	--	0.73
Resolute Bay						
2	(2-3)	--	--	--	--	0.80±0.04 (0.77-0.83)
Pangnirtung						
6	(11-12)	0.88±0.69 (0.39-1.37)	0.33±0.15 (0.22-0.43)	33.63±4.99 (30.10-37.15)	0.03±0.01 (0.02-0.05)	0.62±0.27 (0.27-1.08)

1 Individual data for this table are given in Table 4A, Appendix.
2 n = Number of samples.
3 dashes indicate too little sample available for analysis.

Table 6. Average metal concentrations ± SD, and range( ) in tissues of various fishes from Tuktoyaktuk Harbour (µg/g, wet wt)[1].

n[2]	Spec.	Age	Cu	Cd	Zn	Hg	Se
liver[3]							
1	BW	(13+)	28.39	<0.50	40.30	0.08	0.68
2	PH	(5)	5.34	0.86	30.61	0.05±0.03 (0.03-0.07)	3.27±0.90 (2.63-3.90)
2	AF	(6)	5.04	<0.50	37.20	0.03+0.00 (0.03-0.03)	1.61+0.35 (1.36-1.85)
2	FS	(8-13)	3.30±1.21 (2.44-4.15)	0.56±0.02 (0.54-0.57)	40.09±1.41 (39.09-41.09)	0.19±0.06 (0.14-0.23	1.11±0.17 (0.99-1.23)
muscle							
2	BW	(13+)	0.48±0.32 (0.25-0.70)	<0.05	14.40±0.98 (13.70-15.09)	0.02±0.01 (0.01-0.03)	0.39±0.19 (0.25-.052)
2	PH	(5)	0.93±0.11 (0.85-1.01	<0.05	6.99±0.48 (6.65-7.33)	0.02±0.00 (0.02-0.02)	0.51±0.06 (0.46-0.55)
2	AF	(6)	0.46±0.20 (0.32-0.60)	<0.05	16.35±4.03 (13.50-19.20)	0.03±0.01 (0.02-0.04)	0.49±0.04 (0.46-0.51)
2	FS	(8-13)	0.95±0.06 (0.90-0.99)	<0.05	20.64±1.17 (19.81-21.46)	0.18±0.03 (0.16-0.20)	0.37±0.01 (0.36-0.37)
kidney							
2	BW	(13+)	0.76±0.37 (0.49-1.02)	0.09±0.06 (0.04-0.13)	46.81±2.62 (44.96-48.66)	0.06±0.01 (0.05-0.06)	1.21±1.01 (0.49-1.92)
2	PH	(5)	--[4]	--	--	--	2.95+0.01 (2.94-2.95)
2	AF	(6)	--	--	--	--	1.03±0.04 (1.00-1.05)
1	FS	(8+)	--	--	--	--	0.85
gonads							
2	BW	(13+)	2.64±3.36 (1.67-3.60)	0.13±0.01 (0.12-0.14)	65.47±51.17 (29.29-101.7)	0.03±0.01 (0.02-0.04)	0.90±0.64 (0.44-1.35)
2	PH	(5)	1.52±0.41 (1.23-1.81)	0.04±0.00 (0.04-0.04)	21.95±12.64 (13.01-30.89)	0.01±0.00 (0.01-0.01)	1.49±1.09 (0.72-2.26)

Table 6 continued

2 AF	(6)	0.45±0.11 (0.37-0.53)	0.05±0.03 (0.03-0.07)	49.91±48.85 (15.37-84.45)	0.03±0.01 (0.02-0.03)	0.60±0.23 (0.44-0.76)
2 FS	(8-13)	0.53±0.05 (0.49-0.56)	0.06±0.01 (0.05-0.07)	23.18±5.37 (19.38-26.97)	0.09±0.08 (0.03-0.14)	1.45±0.05 (1.41-1.48)

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1 Individual data for this table are given in Tables 5A, 6A, 7A, and 8A, Appendix.

2 n = Number of samples.

3 BW = Broad Whitefish, PH = Pacific Herring, AF = Arctic Flounder, FS = Fourhorn Sculpin.

4 dashes indicate too little sample available for analysis.

Table 7. Average metal concentrations ± SD, and range( ) in tissues of Greenland Cod from Cambridge Bay (µg/g, wet wt)[1].

n[2]	Age	Cu	Cd	Zn	Hg	Se
liver						
6	--	15.94±8.13 (4.99-28.71)	<0.50 (<0.50)	28.10±3.95 (22.22-32.42)	0.04±0.02 (0.03-0.07)	1.14±0.21 (0.88-1.47)
muscle						
7	--	0.45±0.21 (0.23-0.81)	<0.05 (<0.05)	6.58±4.80 (3.26-17.10)	0.04±0.01 (0.02-0.05)	0.33±0.05 (0.24-0.37)
kidney						
7	--	--[3]	--	--	0.17 (0.17)	(1.10±0.09) (0.95-1.20)
gonads						
7	--	0.47±0.12 (0.37-0.69)	0.03±0.01 (<0.02-0.04)	60.06±24.75 (18.31-85.82)	0.02±0.00 (0.01-0.02)	0.88±0.20 (0.65-1.26)

[1] Individual data for this table are given in Table 8A, Appendix.
[2] n = Number of samples.
[3] dashes indicate too little sample available for analysis.

Table 8. Average metal concentrations ± SD, and range( ) in tissues of various fish from Resolute Bay (µg/g, wet wt)[1].

n[2]	Spec.	Age	Cu	Cd	Zn	Hg	Se
liver[3]							
1	FS	---	--[4]	--	--	--	0.15
2	FD	(12-13)	--	--	--	0.06	0.59±0.37
muscle							
1	FS	---	--	--	--	0.05	0.25
2	FD	(12-13)	0.70±0.15 (0.59-0.80)	<0.05	13.29±1.60 (12.16-14.42)	0.08±0.01 (0.07-0,08)	0.29±0.08 (0.23-0/34)
kidney							
1	FS	---	--	--	--	--	0.56
2	FD	(12-13)	--	--	--	--	0.55±0.06 (0.51-0.59)
gonads							
2	FD	(12-13)	--	--	--	--	0.26±0.13 (0.17-0.35)

[1] Individual data for this table are given in Table 8A, Appendix.
[2] n = Number of samples.
[3] FS = Fourhorn Sculpin, FD = Fish Doctor.
[4] dashes indicate too little sample available for analysis.

Table 9. Reference metal concentrations in fish tissues (µg/g wet wt).

Fish species and number of fishes analysed ()	Pb	Cu	Cd	Hg	Se	Zn	source
Lake trout (10) muscle	0.012	0.46	0.002	0.51	0.41	3.61	1
Northern Pike (7) liver	0.02	5.42	0.03	0.03	--	28.64	2
Northern Pike (20) muscle	0.03	0.28	0.08	0.09	--	6.72	2
Burbot (6) liver	<0.10	6.50	0.15	0.03	1.14	13.9	3
Burbot (9) liver	<0.10	24.7	0.26	0.09	1.86	40.7	3
Burbot (16) muscle	<0.05	0.21	<0.01	0.27	0.40	5.05	3
Inconnu (1) liver	<0.10	15.3	<0.10	0.09	1.05	24.2	3
Inconnu (2) muscle	<0.05	0.14	<0.01	0.10	0.41	2.75	3
Lake whitefish (7) muscle	<0.05	0.18	<0.01	0.11	0.39	3.30	3
Arctic cod (7) muscle	--	0.8	<0.1	--	--	6.8	4
Arctic cod (7) liver	--	0.6	0.13	--	--	3.8	4

1 Fishes from Lake Superior; data from: Armstrong F.A.J. and A. Lutz, 1977. Lake Superior, 1974: PCB, Chlorinated Insecticides, Heavy metals and Radioactivity in Offshore Fish. Can. Fish. Mar. Serv. Tech. Rep. 693: vi+17p.

2 Fishes from various locations (averaged) in the Mackenzie River; data from: Hatfield C.T., J.N. Stein, M.R. Falk, C.S. Jessop and D.N. Shepherd. 1972. Fish Resources of the Mackenzie River Valley Interim Report 1. Environ. Can. Fish. Serv. Winnipeg 2: x+289p.

3 Fishes from the Mackenzie River at Fort Good Hope; unpublished date from a report prepared by R. Wagemann, DFO, Winnipeg.

4 Results of Bohn and McElroy (1976) converted to a wet weight basis assuming moisture content of 80%.

Organochlorines. Results of recovery studies (Table 10) indicated that there were few losses of organochlorines during extraction, gel permeation and Florisil chromatography steps. Greater than 100% recoveries at the low level fortification (3 ng/g) were due to substantial interference from background levels of organochlorines in the fish muscle used. It is difficult to find fish tissues free of low ng/g concentrations of organochlorines.

Results of the analysis of organochlorines in pooled Arctic marine fishes are summarized in Table 11. Levels of specific isomers are tabulated in the Appendix (Tables 9A - 12A). These sample extracts have been chromatographed on two different instruments and Fractions 1 and 2 from two of the samples were analysed by GC-MS-SIM. Chromatograms obtained for four of the samples are shown in Fig. 2 and 3. GC-MS results for Resolute Bay Arctic cod extracts and Tuktoyaktuk Pacific herring are presented in Fig. 4 - 9.

Seven chlordane-related isomers were detected in Greenland and Arctic cod muscle samples (Appendix Table 9A) at sub-ng/g levels. Trans-nonachlor and cis-chlordane were the major chlordane components. U3 is an additional trans-nonachlor isomer first reported by Norstrom et al. (1985) in polar bear fat (Fig. 6). Concentrations of total chlordane (s-chlordane) were similar to those of s-DDT and s-PCB (Table 11) ranging from 0.5 to 5.6 ng/g wet wt. Several chlordane isomers reported in Hawaiian fishes by Ribicki and Zajicek (1983) were not detected in Arctic cod or Pacific herring although several unidentified peaks at m/e 272 in SIM chromatograms (Fig. 6 and 7) suggest the presence of other isomers. Among the fish samples analysed (Table 11), flounder and whitefish from Tuktoyaktuk harbour are distinguished by lower s-chlordane levels than Pacific herring or inconnu from the same site and from Arctic cod in the eastern Arctic.

HCH isomers varied greatly between sites ranging from 18.1 ng/g in Arctic cod from Arctic Bay to 0.2 ng/g in Greenland cod at Cambridge Bay (Table 11). Alpha-HCH was the major isomer present (Table 9A). Herring at Tuktoyaktuk had much higher levels than other fishes indicating that species differences in ability to metabolize HCH isomers may also be important.

Peaks corresponding to toxaphene were observed in GC (electron-capture detector) chromatograms of Florisil Fraction 2 of several fish samples (Fig. 2 and 9) and were confirmed by SIM of herring muscle extracts (Fig. 9). Results for toxaphene can only be considered semi-quantitative because only six peaks, consisting of higher chlorinated toxaphene congeners, out of a total of 75 or more in the analytical standard, could be identified. By assuming the 6 peaks

in the standard were equivalent to the entire standard we may have overestimated the amount of toxaphene present. Relatively high levels of toxaphene (compared with PCBs, DDT or chlordane) were found in Pacific herring and inconnu muscle from Tuktoyaktuk and in Arctic cod from Arctic Bay and Pangnirtung (Table 11). Some samples, eg. flounder and whitefish muscle, contained no detectable toxaphene (Fig. 3).

Total DDT isomers were present at levels similar to s-chlordane ranging from 0.41 to 6.34 ng/g in fish muscle (Table 10A). The o,p'-DDT isomer was detected in most samples (and confirmed by GC-MS SIM, Fig. 6) from the Eastern Arctic and in Pacific herring. The presence of the o,p'-DDT isomer in fish is indicative of the input of technical DDT which contains about 20% of the o,p-isomer (Zell et al., 1978). DDE comprised an average 44% of s-DDT (range 11-79%) in the fish samples (Table 10A). The p,p'-isomer was, along with alpha-HCH, one of the highest individual residues in the samples particularly in Greenland cod and in Pacific herring (Table 10A).

Forty-eight tri- to heptachlorobiphenyls were detected in Arctic cod from Resolute Bay and Arctic Bay, by GC-MS-SIM analysis (Fig. 4, 5 and 8). Trichloro- biphenyls could not be quantitated by GC-ECD although present at relatively high (sub-ng/g) levels, because of low instrumental response factors for these isomers. Table 11A includes all isomers and co-eluting congeners quantitated by GC-ECD and Table 12A includes additional isomers quantitated only by SIM. A listing of the structures of the isomers corresponding to the PCB numbering used here is given in Table 13A. Total PCB isomers (s-PCB), excluding trichlorobiphenyls, were present at a similar range of concentration as DDT and chlordane, as indicated by DDT/PCB and chlordane/PCB ratios near 1 (Table 10A). Exceptions to this were whitefish and flounder from Tuktoyaktuk harbour which had DDT/PCB ratios of 0.22 and chlordane/PCB ratios of 0.11 to 0.26.

Polyaromatic hydrocarbons. Recoveries of all PAH standards except naphthalene ranged from 74 to 90% in fortified fish samples (Table 13). Low recoveries of naphthalene were likely due to evaporative losses during solvent concentration steps. Enviro-Test (1984) reported low recoveries (20-50 %) of volatiles n-hexadecane, cumene and mesitylene, using the same extraction and chromatographic procedures as those used in this study, but recovery of 2-methyl naphthalene averaged 102%. Concentrations of individual PAH in fish muscle (or whole fish) quantitated by HPLC-UV and FD are reported in Table 14.

Table 10. Recovery of organochlorines from fortified fish muscle.

Compound	Concentration (ng/g)	Recovery (% ± S.D.)
1,2,4,5-tetrachlorobenzene	21	77 ± 23
	4	85 ± 7
	1[1]	124 ± 42
pentachlorobenzene	20	85 ± 23
	4	97 ± 12
	1	139 ± 53
hexachlorobenzene	20	90 ± 25
	4	101 ± 5
	1	143 ± 58
oxychlordane	60	92 ± 4
	15	105 ± 6
	3	133 ± 26
p,p'-DDE	60	86 ± 12
	15	115 ± 15
	3	118 ± 30
p,p'-DDT	60	80 ± 13
	15	111 ± 22
	3	113 ± 19
mirex	40	75 ± 18
	10	102 ± 13
	2	101 ± 25

[1] Pike muscle contained sub-ng/g concentrations of all organochlorines resulting in >100% recoveries at low spike level.

Table 11. Organochlorine concentrations in arctic marine fishes (ng/g wet wt).

Location	Pool No.	s-HCH[1]	HCB	s-DDT[2]	s-chlordane[3]	s-PCB[4]	toxaphene
Arctic Bay	1	18.1	1.2	1.9	2.0	2.6	23
	2	11.9	1.0	0.7	1.4	<1.0	<2
Resolute Bay	1	2.0	2.5	2.4	3.1	4.7	14
Pangnirtung	1	6.1	1.0	6.3	3.4	4.5	46
Tuktoyaktuk	1	<0.1	0.1	0.4	0.5	1.9	<2
	3	12.5	0.6	5.0	5.6	4.1	74
	4	0.2	0.1	1.1	0.5	4.6	<2
	5	0.2	0.4	2.5	3.3	3.5	24
Nauyak (Cambridge Bay)	1	1.2	0.3	1.8	1.1	3.7	<2
	2	0.2	0.3	2.2	1.3	3.0	<2
Frobisher Bay	1	0.3	0.9	2.8	0.7	2.3	6
	2	0.5	0.7	2.1	1.2	4.1	<2

[1] Sum of alpha and gamma-HCH.
[2] Sum of p,p'-DDE, p,p'-DDD, p,p'-DDT, o,p'-DDT.
[3] Sum of oxychlordane, cis-chlordane, trans-nonachlor, U3, cis-nonachlor, and heptachlor epoxide.
[4] Sum of PCB isomers 52,49,70,95,99,101,110,118,146,149,153,138,170,183,187.

Table 12. Total PCB homologs (ng/g wet wt.) and percent of s-PCB in arctic marine fishes.

		Cl_4 [1]		Cl_5		Cl_6		Cl_7	
		ng/g	%	ng/g	%	ng/g	%	ng/g	%
Arctic Bay	1+2	0.49	27	0.64	35	0.53	29	0.18	10
Resolute	1	0.33	9	1.00	27	1.80	49	0.56	15
Pangnirtung	1	1.27	28	1.23	27	1.42	32	0.57	13
Tuktoyaktuk	1	0.35	19	0.58	32	0.64	35	0.26	14
	3	1.28	31	1.35	32	1.16	28	0.40	10
	4	0.92	20	1.31	28	1.56	33	0.88	19
	5	0.51	15	1.26	37	1.21	36	0.42	12
Cambridge Bay	1+2	0.57	18	0.94	29	1.25	39	0.45	14
Frobisher Bay	1+2	0.99	27	1.19	32	1.24	33	0.29	8

[1] includes only tetras quantitated by GC-ECD. Where peaks overlap e.g., 66/95 ratio from SIM used to assign contribution to each homolog.

Figure 2. Chromatograms of arctic marine fish extracts (Fraction 1) analysed by capillary GC with electron-capture detection.

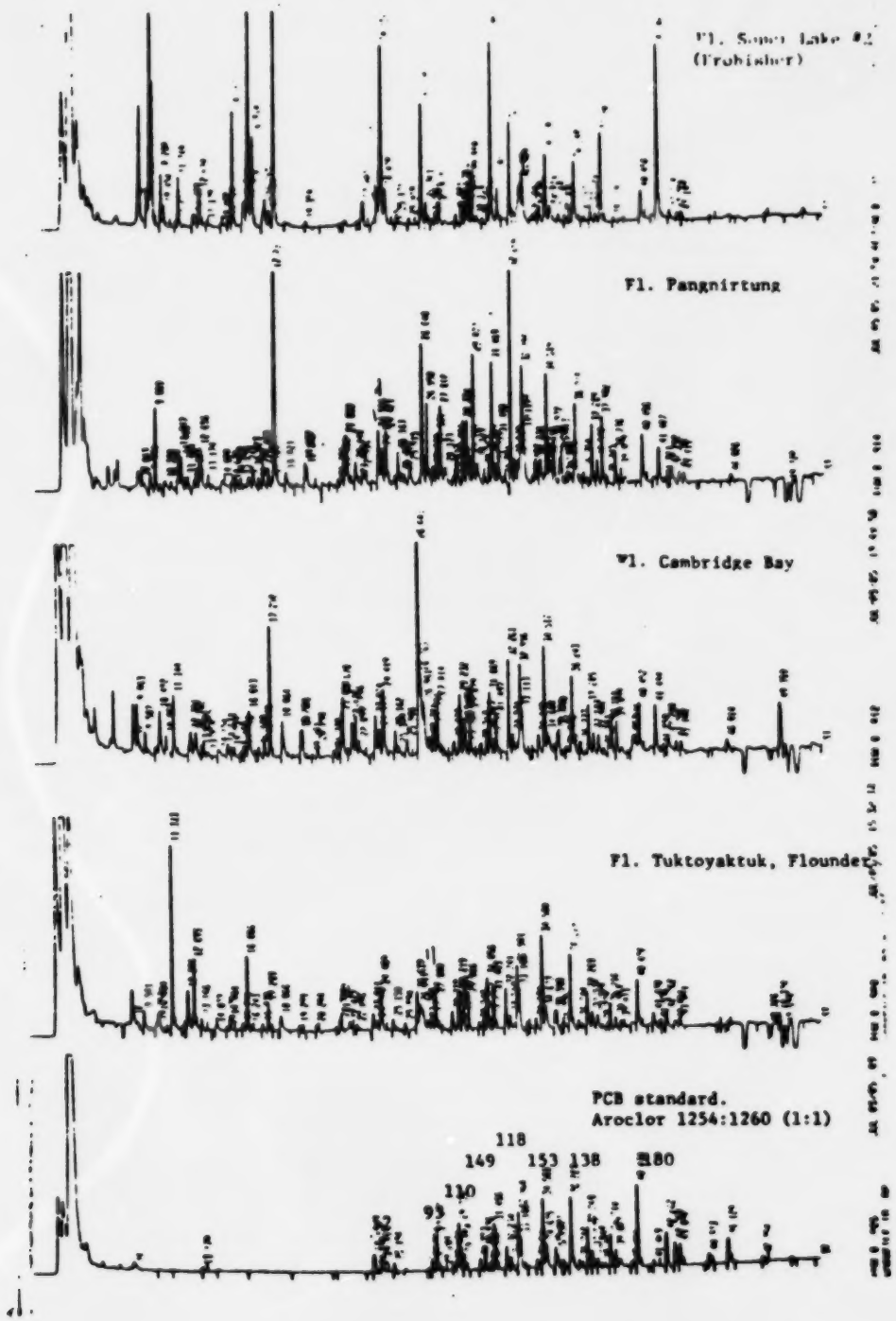


Figure 3. Chromatograms of arctic marine fish extracts (Fraction 2) analysed by capillary GC with electron-capture detection.

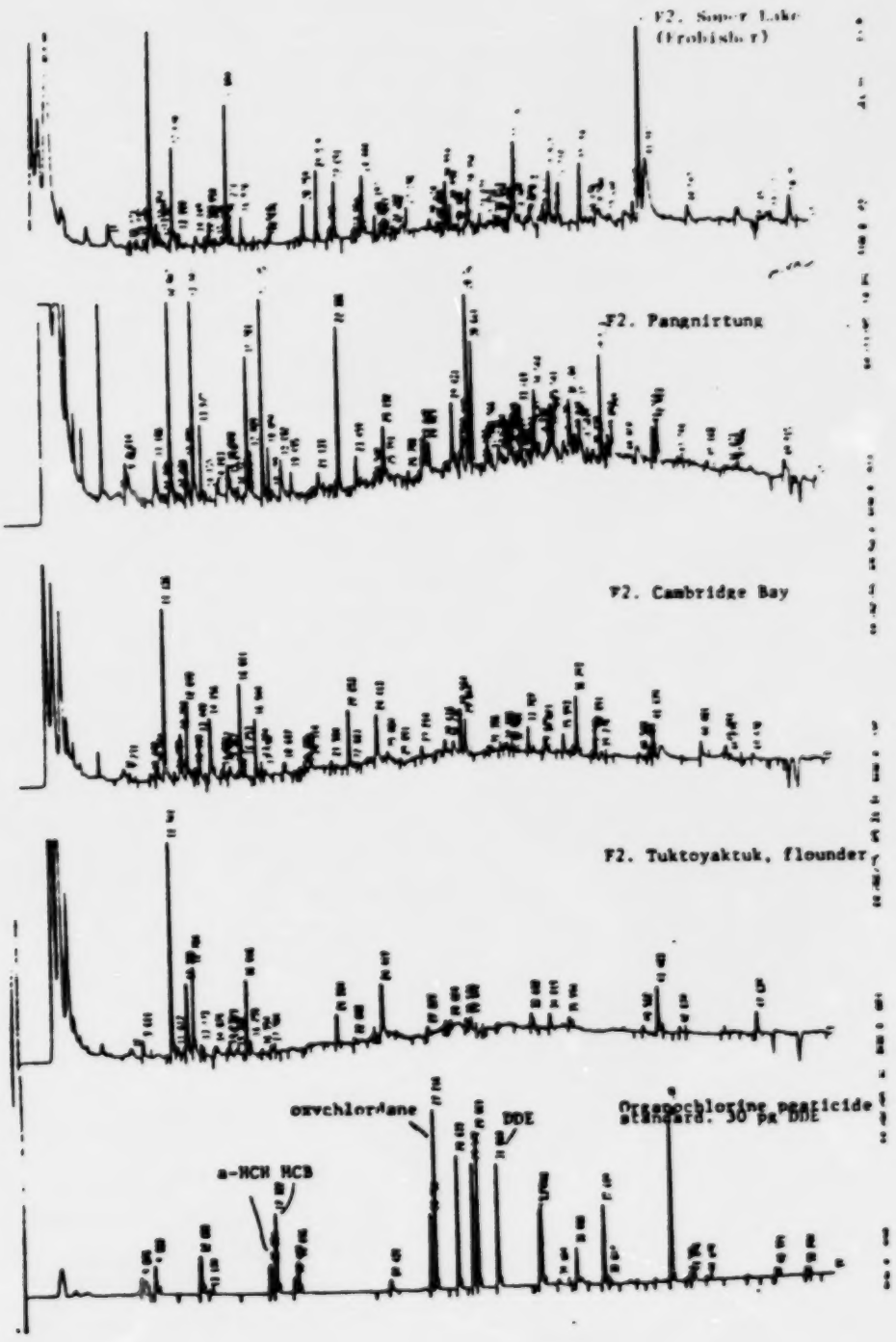


Figure 4. PCB isomer confirmation by GC-MS SIM. Fraction 1 - Arctic cod Resolute Bay.

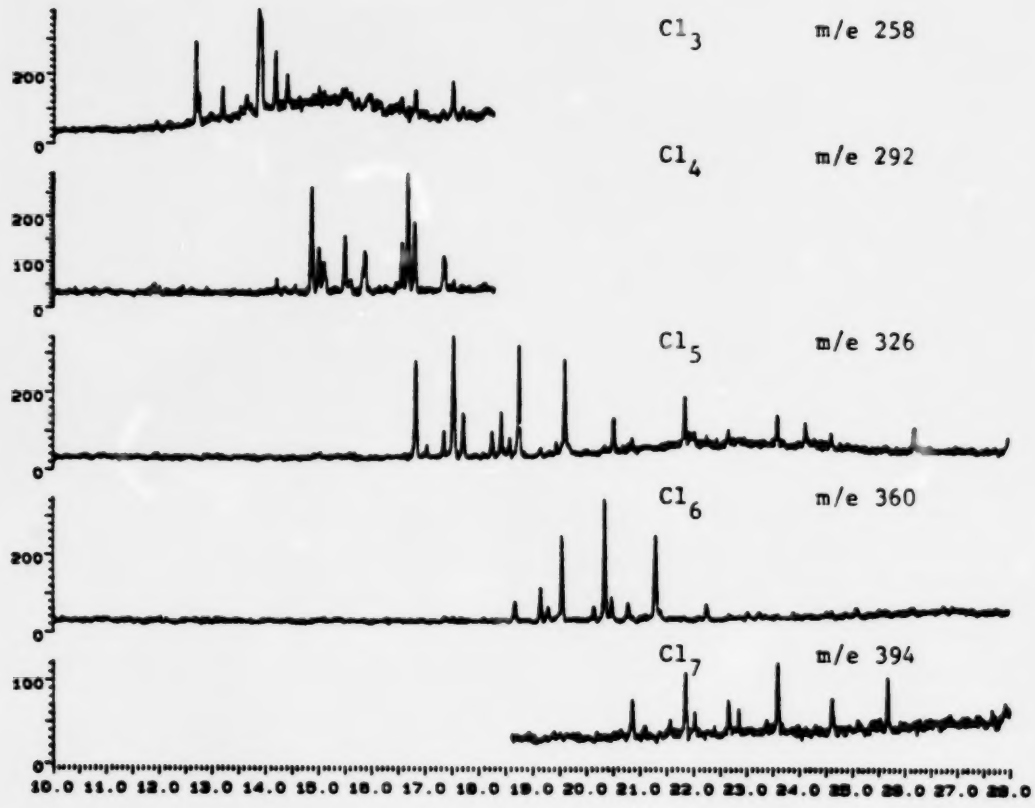


Figure 5. PCB standard by GC-MS SIM. Arochlor 1254:1260 (1:1).

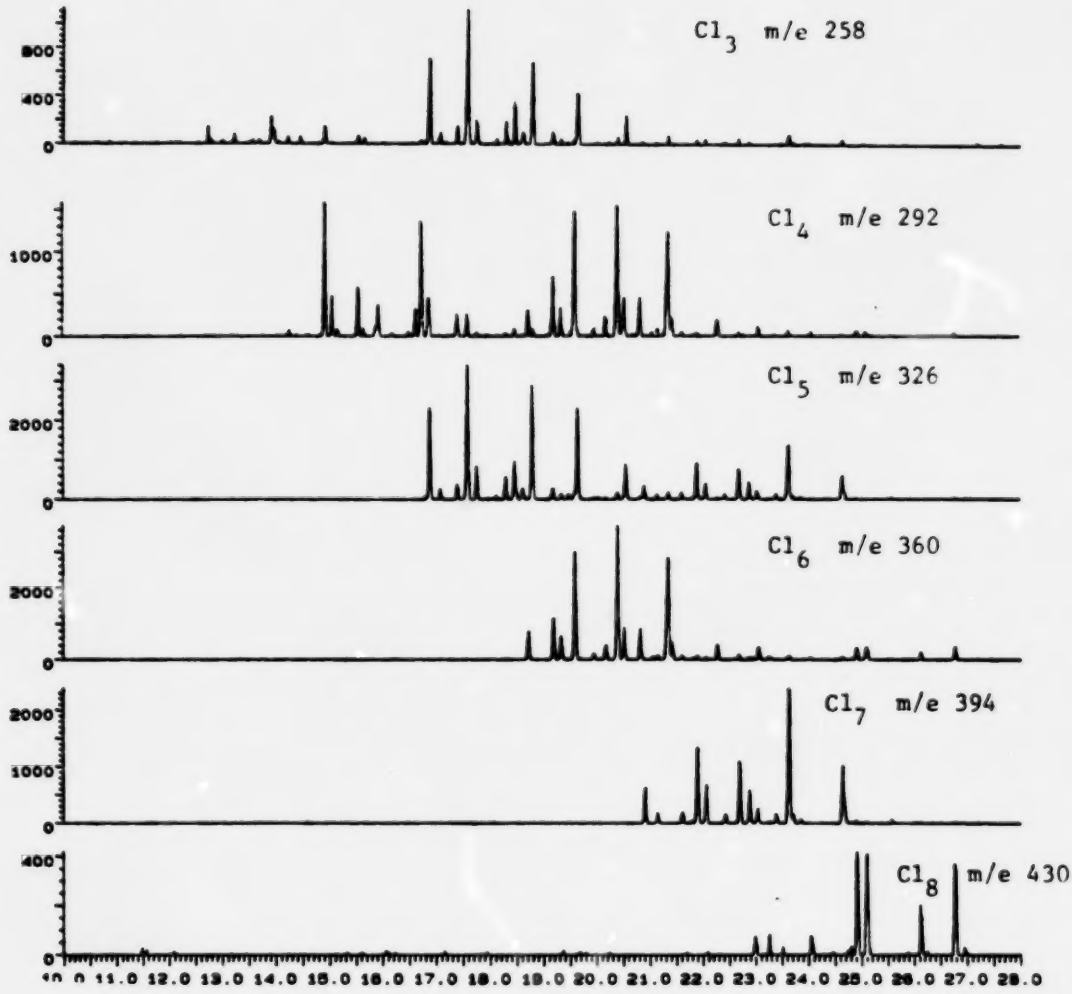


Figure 6. Confirmation of chlordane related compounds by GC-MS SIM of fraction 1 and 2 - Arctic cod from Resolute Bay.

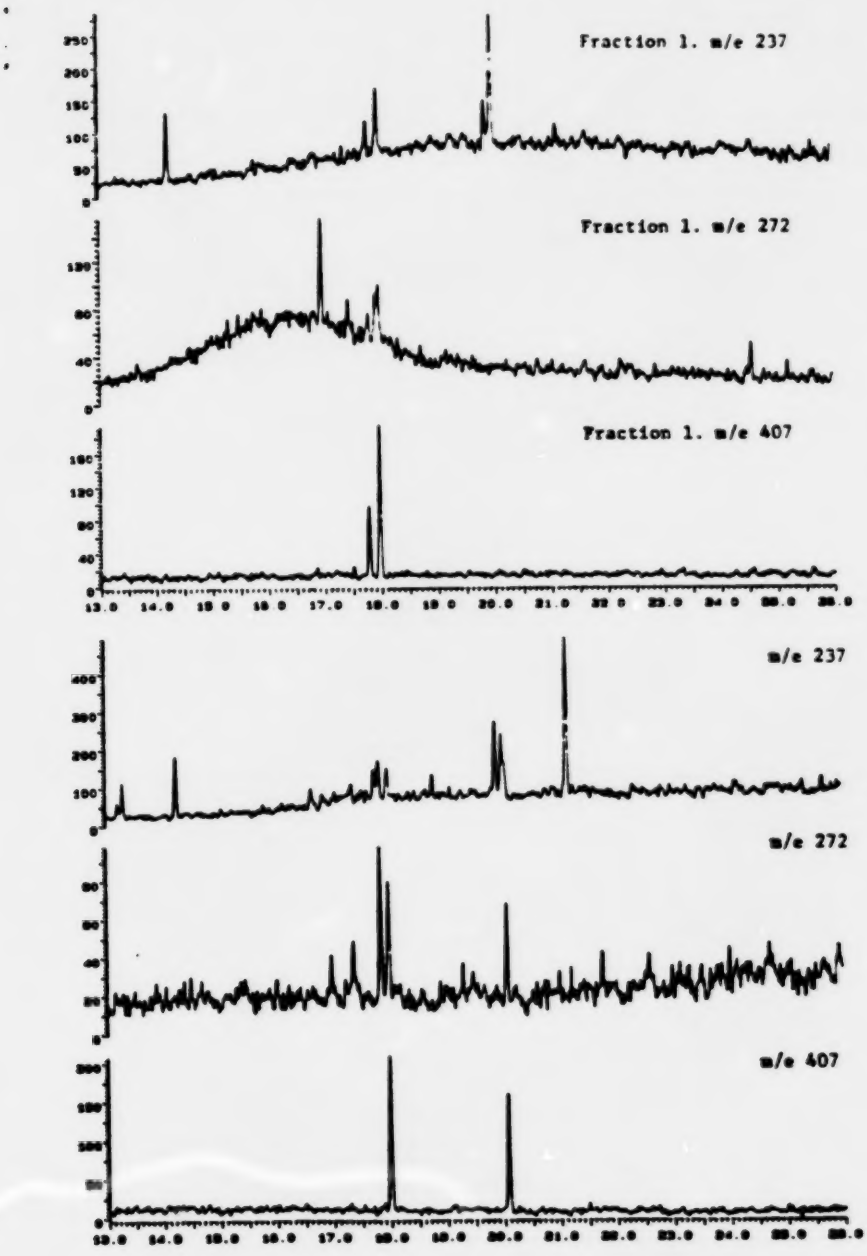
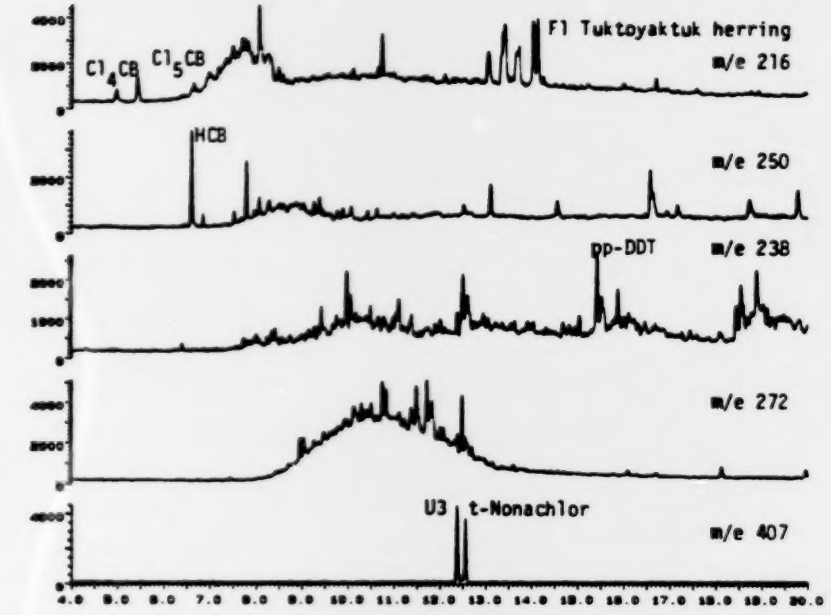


Figure 7. Confirmation of HCH, HCB and chlordane related compounds in Pacific herring muscle extracts from Tuktoyaktuk by GC-MS SIM.



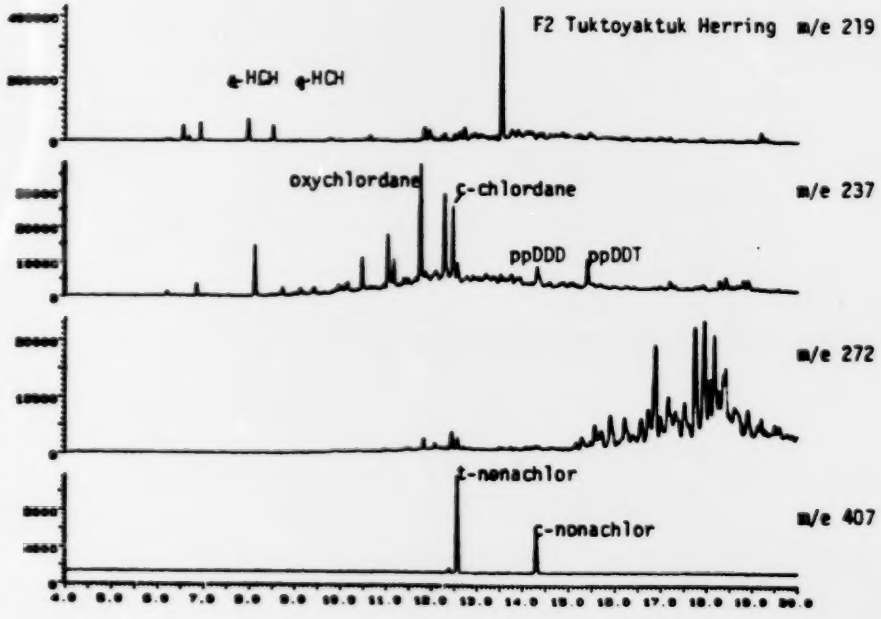


Figure 8. PCB isomers in Pacific herring muscle extracts from Tuktoyaktuk by GC-MS SIM.

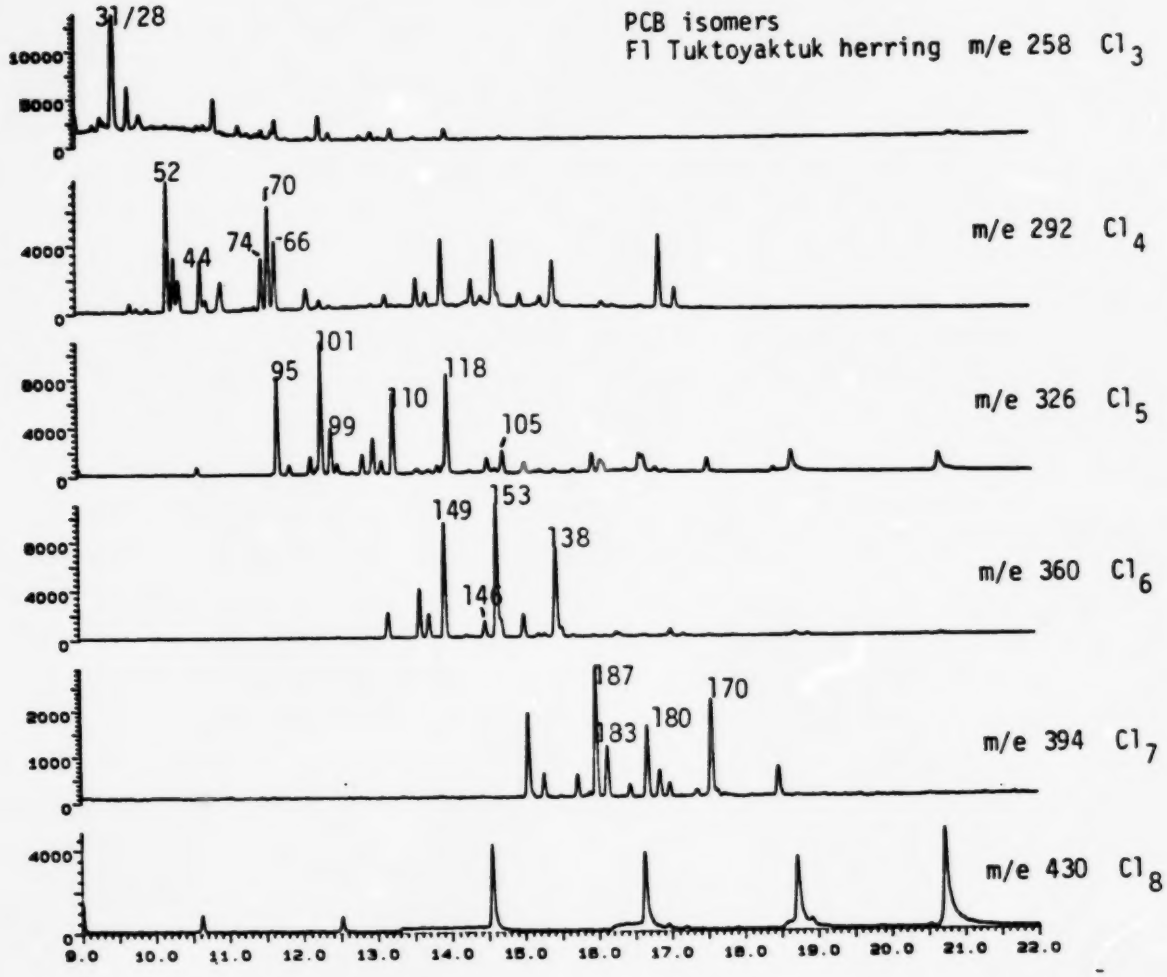
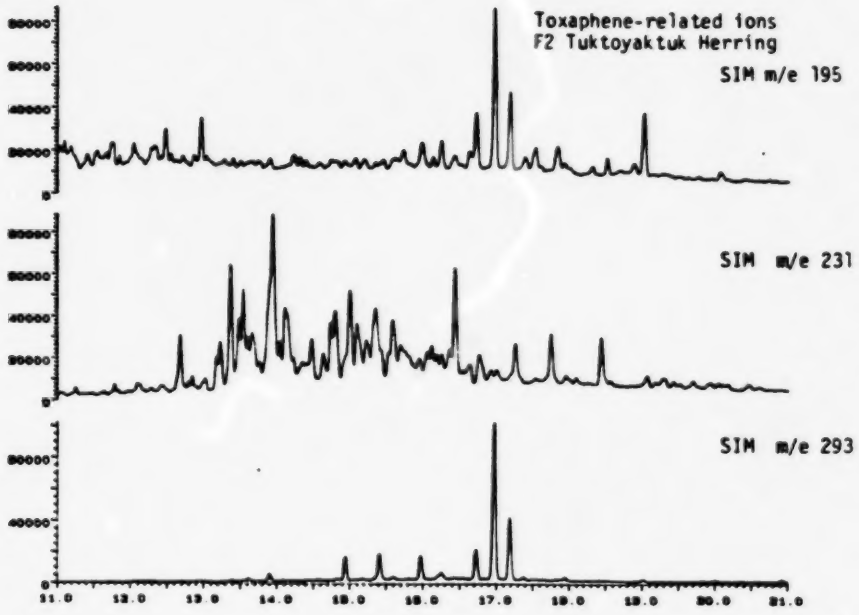
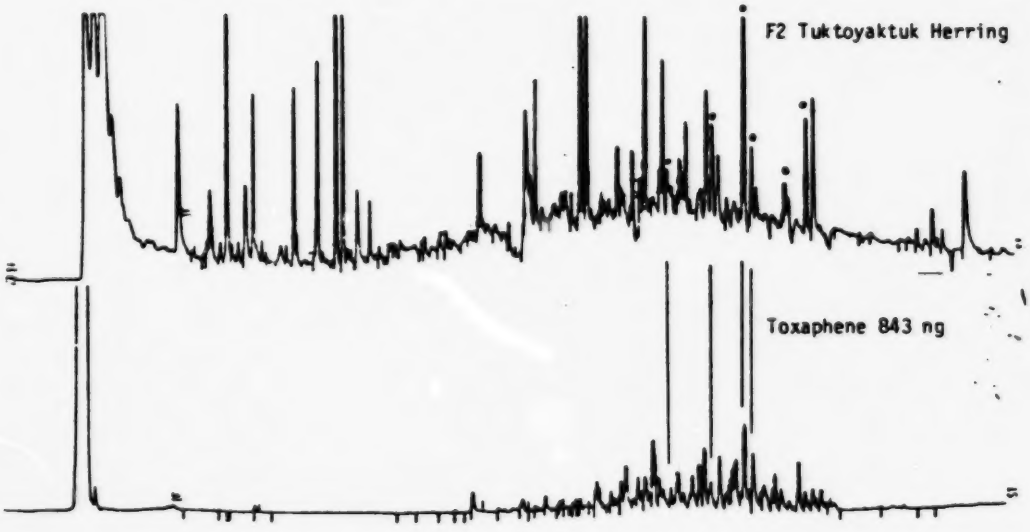


Figure 9. Toxaphene-related compounds in Pacific herring extracts from Tuktoyaktuk by GC-MS SIM (upper chromatograms) and capillary GC-ECD.





Only priority pollutant PAHs (Kinzer et al., 1984) for which we had analytical standards were quantitated. HPLC-UV chromatograms for two of the samples are presented in Fig. 10. Three and four ringed PAH, fluoranthene and phenanthrene could be routinely confirmed by HPLC-FD using excitation at 280 nm and emission at 289 nm (Fig. 11) as well as by GC-MS-SIM. Procedural blanks were free of UV absorbing or fluorescent peaks at the retention times of any aromatics with two or more rings.

Naphthalene was the major two-ringed PAH detected in fish muscle extracts (Table 14). Concentrations of naphthalene are not corrected for recovery efficiency. Naphthalene was not detected (<2 ng/g) in inconnu muscle from Tuktoyatuk harbour but was present at similar levels (3.7 - 6.3 ng/g) in all Arctic cod from Resolute Bay. Enviro-test (1984) detected naphthalene in flounder and whitefish from Tuktoyaktuk harbour at concentrations ranging from <5 to 25 ng/g and in Pacific herring collected in Liverpool Bay (100 km east of Tuktoyaktuk) at <5 to 37 ng/g. GC-MS-SIM analyses indicated the presence of methyl and dimethyl-naphthalenes at similar levels to naphthalene (Fig. 12) but these were not quantitated because of lack of suitable standards.

Phenanthrene was present at concentrations ranging from 0.6 to 8.1 ng/g in the fish muscle analysed (Table 14), the highest concentrations of any 3 or 4 ringed PAHs. Levels of phenanthrene showed little geographic variation. There was a 10-fold variation in phenanthrene concentrations within the five Arctic cod analysed. Methylphenanthrene peaks (at least four isomers) were detected in both inconnu and Arctic cod samples at similar levels to phenanthrene based on the total peak area (Fig. 12).

Fluoranthene and pyrene were also detected by HPLC-FD and confirmed by GC-MS-SIM in most of the samples that were analysed although at lower levels than phenanthrene or naphthalene (Table 14).

Mixed-function oxidase enzymes. MFO activities were detected in all the liver samples analyzed (Table 16). BaP hydroxylase activities were found in all samples, but livers from fish frozen whole in the field tended to have somewhat lower activities than livers from fish dissected and frozen on dry ice in the field, although the sample size was too small for a firm conclusion. O-deethylase activities were measurable in about half the field-dissected samples but not in any of those frozen whole. O-demethylase activities were present in both groups of livers, but again no firm conclusion

Table 13. Recoveries of PAHs from fortified fish muscle

Compound	Concentration (ng/g)	Recovery (% ± S.D.)
naphthalene	50	39 ± 10
fluorene	50	74 ± 4
phenanthrene	50	80 ± 8
anthracene	50	80 ± 8
fluoranthene	50	76 ± 8
methylphenanthrene	50	95 ± 12
pyrene	50	76 ± 11
benzo(a)phenanthrene/benzo(a) anthracene[1]	50	80 ± 6

[1] co-eluting peaks by HPLC.

Table 14. PAH concentrations in Arctic marine fish muscle (ng/g wet wt).

Compound	Concentration (ng/g wet wt) in each sample (Field No.)						
	Tuktoyaktuk/Inconnu		Resolute Bay/Arctic cod				
	1	4	78	79	80	81	82
naphthalene	<1.0	<1.0	6.3	5.4	5.0	5.1	3.7
phenanthrene	1.1	1.3	4.0	0.6	7.9	8.1	0.8
anthracene	<0.1	<0.1	<0.1	<0.1	0.5	0.5	<0.1
fluoranthene	0.3	0.2	0.5	<0.1	1.0	1.1	0.1

is warranted yet on whether the different dissection practises had much influence on the results. Overall, the results suggest use of some means of rapid freezing in the field, notably dry ice or liquid nitrogen. While the comparison between these groups argues for rapid freezing in the field, it does not establish that either method is free from storage artifacts.

DISCUSSION

Metals. The large standard deviations associated with mean concentrations of Zn and Cu do not arise from large analytical variances and are, most likely, a consequence of variations in lipid and moisture content of tissues from different fish. Although some geographic variation in concentrations is to be expected the concentration of these essential metals is homeostatically controlled in most organisms and would therefore be expected to vary only within fairly narrow limits. Some reduction in variance would have been achieved if it had been possible to express concentrations on a dry weight basis but, due to scarcity of sample, fat and moisture were not determined as adjunct to trace metal determinations (although they were measured on a limited number of extracts for organic contaminants). Relationships between metal concentrations and location, fat and moisture content could therefore not be investigated statistically. Liver of cod are generally high and variable in lipid content which influences the metal concentrations in that tissue (Grimas et al., 1985). This arises because most metals are stored preferentially in proteinaceous tissue rather than fatty tissue and the latter acts as a diluent of metals when these are expressed as concentration on a unit weight basis of total tissue. Previous work (Wagemann, 1985) has shown that livers of burbot can also be relatively high in fat, and the Cu and Zn concentrations in that organ are then inversely related to fat concentration and vary directly with moisture content.

Zn and Cu concentrations in livers of the marine fishes analyzed in this study were generally similar to published values for northern Canadian freshwater fish (Table 9). However, levels of Zn and Cu in Arctic cod muscle were generally higher than in freshwater species and were similar to levels reported by Bohn and McElroy (1976). Hg concentrations were generally low for all species and all tissues examined in comparison with northern freshwater or anadromous species (Table 9). Cd concentrations were higher than published

Table 15. Mean PAH concentrations (ng/g wet wt; range in parentheses) in fishes from Tuktoyaktuk and from Liverpool Bay (Enviro-Test, 1984).

Location	Species[1]	N	Biphenyl	naphth-alene	CH_3[2] naphth.	anthracene	Phenanthrene/methyl phenanthrene
Tuktoyaktuk	SF	3	5 (<3-14)	13 (<3-25)	24 (<3-39)	19 (15-26)	3 (<3-5)
	AF	3	<3	<3	10 (<3-31)	<3	<3
	LC	4	3 (<3-11)	<3	27 (<3-84)	24 (<3-40)	7 (<3-12)
	WF	2	<3	5 (<3-10)	35 (<3-71)	5 (<3-10)	4 (<3-8)
	EP	3	<3	<3	<3	6 (<5-15)	<3
Liverpool Bay	H	10	4 (<3-20)	2 (<3-13)	6 (<3-47)	12 (<3-26)	4 (<3-33)

[1] SF = Starry flounder; AF = Arctic flounder; LC = Least Cisco; WF = Broad whitefish; EP = Eel pout; H = Pacific Herring.

[2] Sum of dimethyl and trimethylnaphthalenes.

Figure 10. HPLC-UV detector chromatograms of Arctic cod and inconnu muscle extracts and an analytical standard of PAHs.

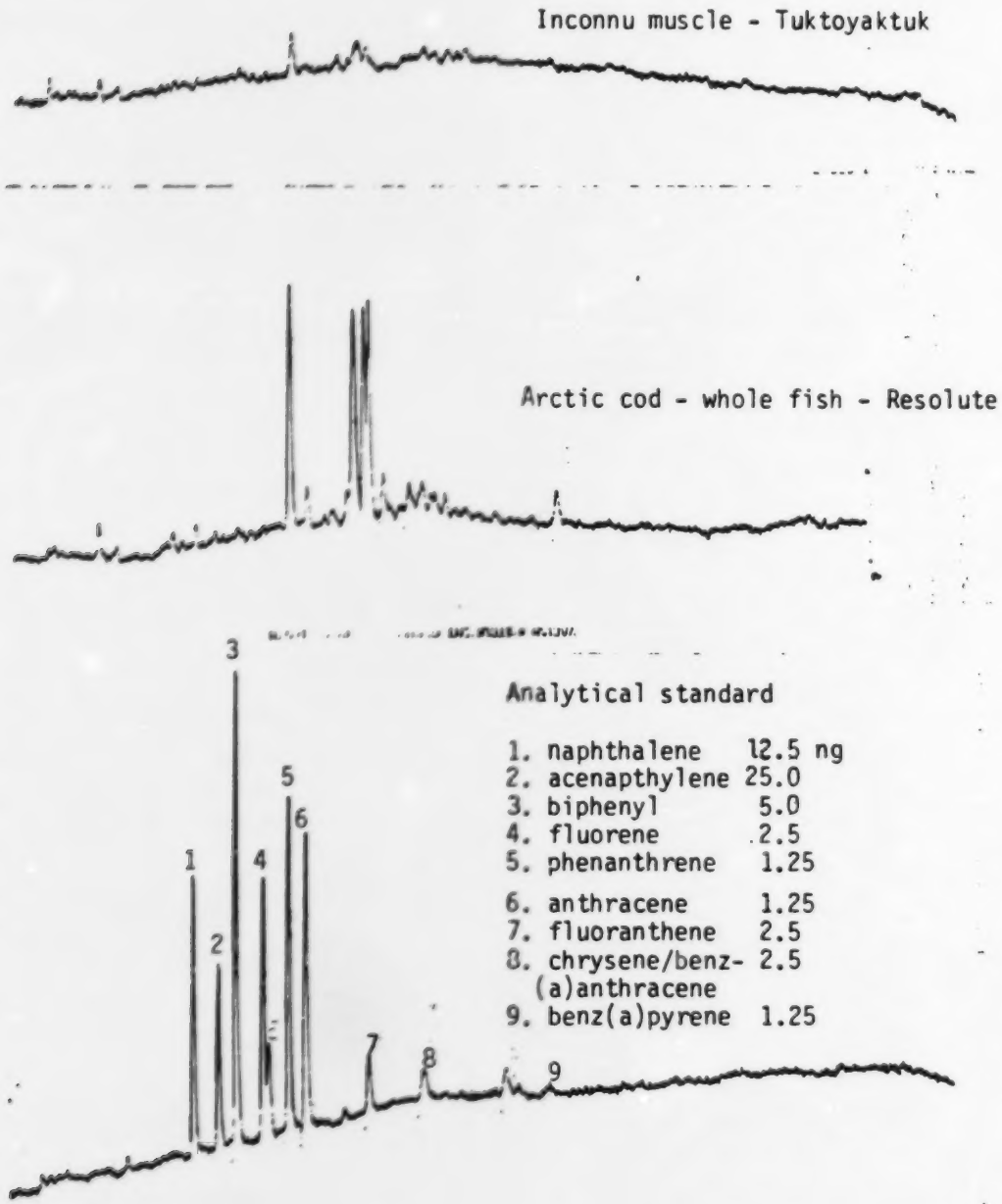


Figure 11. HPLC-FD chromatograms of Arctic cod and inconnu muscle extracts and PAH standard.

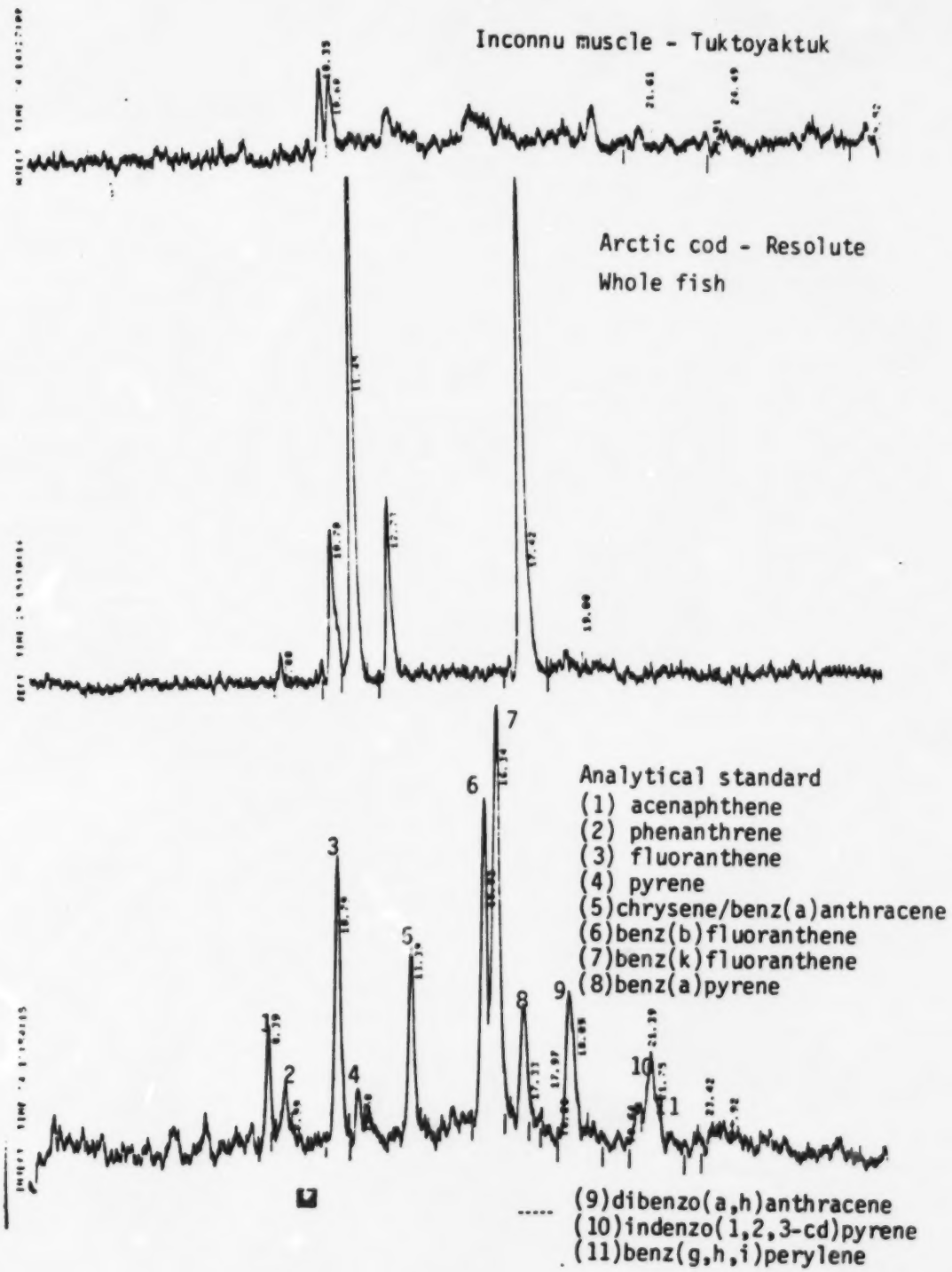
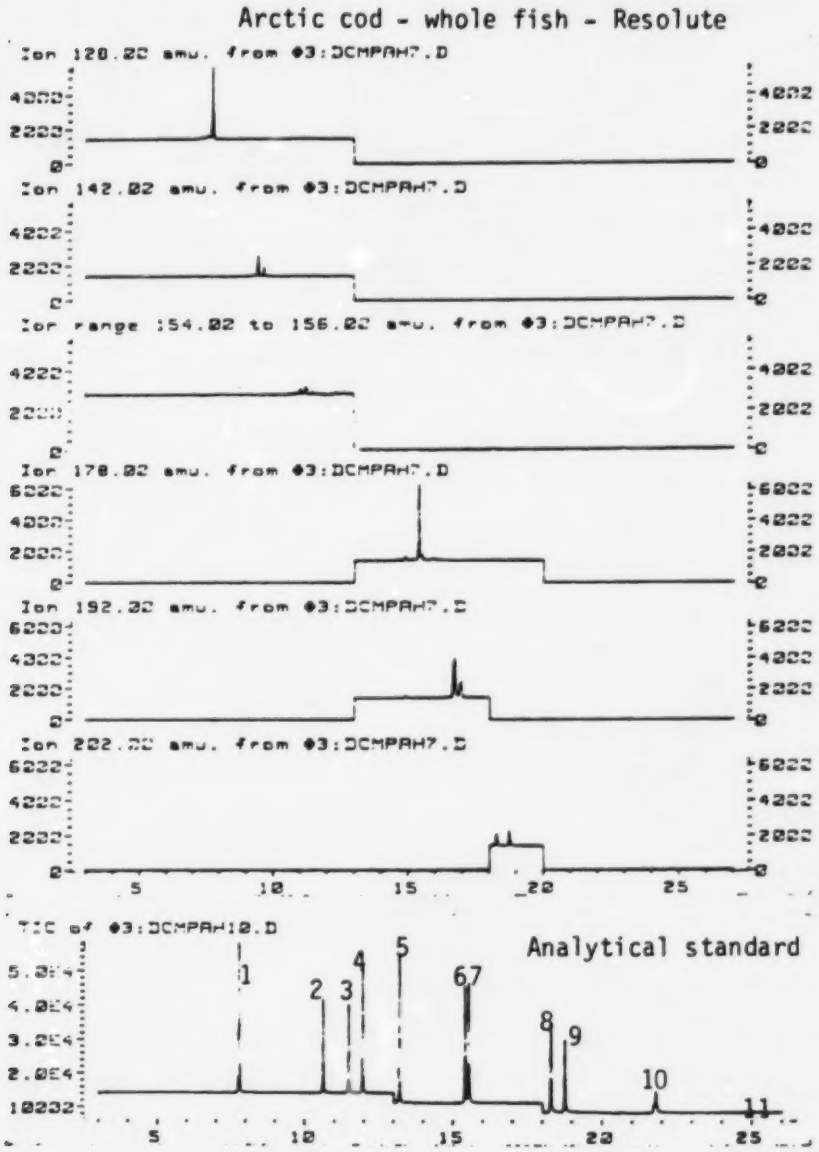


Figure 12. GC-MS-SIM chromatograms of PAHs in an Arctic cod muscle extract. Lower chromatogram is an analytical standard run under identical conditions of 2.5 ng of each compound. (1) naphthalene, (2) acenaphthylene, (3) biphenyl, (4) acenaphthene, (5) fluorene, (6) phenanthrene, (7) anthracene, (8) fluoranthene, (9) pyrene, (10) benzo(a)anathracene and (11) benzo(a)pyrene.



figures (Table 9) in livers of cod (Table 3), Fourhorned sculpins and Pacific herring (Table 9). In all other fish examined, Cd concentrations were low or comparable to reference concentrations (Table 9). Higher Cd in Fourhorn sculpin livers was also reported by Fallis (1982) and Bohn and Fallis (1978). The number of samples available for Cd analysis was too small to allow any general conclusions to be drawn but as with Hg results, these findings merit further investigation particularly in view of the fact that cod forms an important part of the diet of marine mammals, and elevated concentrations in tissues of Narwhals have been reported (Wagemann et al., 1983).

None of the metals, with the exception of Cd, appeared to be abnormally high when compared with concentrations in fishes from other locations (Table 9) and other published literature on contaminants in arctic biota (Muir, 1985). Concentrations of metals other than Hg, in tissues other than muscle or "whole fish", are not frequently published and are particularly limited in the case of arctic species. There is therefore a scarcity of data other than for Hg which can be used for comparative purposes. This information gap should be eliminated by future arctic studies.

Organochlorines. The presence of chlordane and toxaphene isomers in all samples at levels comparable to or higher than DDT and PCB indicates that these compounds have also been transported to arctic marine waters far from sites of use. Chlordane has not been previously reported in arctic freshwater or marine fish as far as we are aware. Direct comparisons of the concentrations with other marine fish from various geographical locations are difficult because more chlordane isomers are monitored in this study and most published data are based on liver analyses. It is apparent, however, that s-chlordane levels in arctic marine fishes are lower than in North Atlantic and Baltic fishes (Zitko, 1973; Moilanen et al., 1982; Skare et al., 1985). For example, cod (Gadus morhua) in Norwegian fiords had 27-fold higher total chlordane (oxychlordane + trans-nonachlor) in livers than Arctic cod muscle from Pangnirtung while Norwegian flounder livers had 8-fold higher levels than flounder muscle at Tuktoyaktuk. The great variation in toxaphene levels among species at Tuktoyaktuk may reflect species differences in lipid content and possibly in the ability to eliminate these chlorinated aliphatic compounds. The pattern of toxaphene peaks in herring and cod was virtually identical to that reported by Musial and Uthe (1983) in Atlantic herring muscle and cod liver. Levels of toxaphene in herring fillets from the Gulf of St. Lawrence

Table 16. Mixed-function oxidase activities in livers of fishes from Tuktoyaktuk Harbour, NWT., Sept., 1984[1]

Species	Sample No. Lab (Field)	BaP Hydroxylase (pmol/mg/min)	ErO Deethylase (nmol/mg/min)	O Demethylase (nmol/mg/min)
Liver dissected and frozen at the time of field collection				
Burbot	8400152 (35)	65.1	<0.022	0.063
Starry flounder	8400146 (20)	13.5	<0.005	0.036
Starry flounder	8400151 (21)	33.5	<0.005	<0.010
Arctic flounder	8400154 (15)	64.6	<0.005	0.072
Lake whitefish	8400142 (10)	78.6	0.004	0.011
Lake whitefish	8400143 (18)	61.1	0.006	0.006
Lake whitefish	8400148 (19)	65.3	0.035	0.010
Lake whitefish	8400155 (17)	16.2	<0.005	0.061
Broad whitefish	8400149 (11)	31.7	<0.005	0.020
Broad whitefish	8400153 (9)	81.4	0.024	0.048
Broad whitefish	8400156 (43)	91.9	0.034	0.133
Inconnu	8400147 (38)	30.5	0.021	0.045
Inconnu	8400150 (36)	13.0	<0.005	0.010
Fish frozen at collection; liver dissected after shipment to Winnipeg				
Lake whitefish	8400159 (33)	22.3	<0.002	0.013
Broad whitefish	8400157 (61B)	7.6	<0.002	0.003
Broad whitefish	8400158 (60)	33.4	<0.002	0.002
Broad whitefish	8400160 (40)	35.8	<0.003	0.004
Broad whitefish	8400161 (32)	19.0	<0.003	<0.002
Broad whitefish	8400163 (37)	3.5	<0.004	0.057
Inconnu	8400162 (30)	2.5	<0.002	0.032
Inconnu	8400164 (31)	4.2	<0.004	0.037

[1] (activities in picomoles or nanomoles of product formed per minute per mg of liver microsomal protein).

Table 17. Approximate microsomal MFO enzyme activities in fishes from some other published studies[1].

MFO activity and Unit of activity	Species	Activity Level	Reference
BaP hydroxylase (pmol/mgP/min)	Coregonus albula	1-15	Lindstrom-Seppa, 1981
	Salmo gairdneri	11	Stegeman et al., 1981
	Salmo gairdneri	1-2290	Ade et al. 1984 (includes induced fish)
	Salmo gairdneri	15	Stegeman and Chevion, 1980
	Micorpogon undulatus	26	Stegeman et al., 1981
	Stenotomus chrysops	250	Stegeman et al., 1981
	Salvelinus fontinalis	8-13 6-31	Law and Addison, 1981 Stegeman and Chevion, 1980
	Salmo gairdneri	22	Elcombe and Lech, 1979
	Esox lucius	12	Balk et al. 1980
	Salmo gairdneri	20	Statham et al., 1978
	Citharicthys sordidus	300-3500	Spies et al. 1982 (includes induced fish)
	Citharicthys stigmaeus	70-260	Spies et al. 1982 (includes induced fish)
Er-O-deethylase (nmol/mgP/min)	Salmo gairdneri	0.1	Stegeman et al. 1981
	Stenotomus chrysops	0.3	Stegeman et al. 1981
	Salmo gairdneri	0.1	Elcombe and Lech 1979
	Salmo gairdneri	0.04	Vodicnik et al. 1981
	Pseudopleuronectes americanus	<2-1165	Foureman et al. 1983 (includes induced fish)
O-demethylase (nmol/mgP/min)	Salmo gairdneri	0.3	Lidman et al. 1976
	Salmo gairdneri	.03-.05	Ade et al. 1984 (includes induced fish)

[1] Values are approximate conversions from techniques and reporting units used by the authors to those used in this report (picomoles or nanomoles product per min per mg liver microsomal protein).

were 1000 ng/g compared with 74 ng/g in Pacific herring at Tuktoyaktuk. Zell and Ballschmiter (1980) reported levels of toxaphene in Antarctic cod liver similar to those in Pacific herring and Arctic cod muscle analyzed in this study. Total PCBs in arctic marine fish muscle (measured either as total isomers or Arochlor equivalents, Table 12A) are much lower than in fishes from the east coast of Canada (Freeman et al., 1984; Sims et al., 1977), Norwegian fiords (Skare et al., 1985), the Baltic (Moilanen et al., 1982) or the Northwest Pacific (Tanabe et al., 1984) but are approximately 10-fold higher than levels in Antarctic fishes (Subramanian et al., 1983). These relatively low levels presumably reflect low ambient concentrations of PCBs in arctic waters and in the marine food chain. No recent measurements of organochlorines in Arctic Ocean waters or in the food chain below fish are available as far as we are aware.

HCH isomers are the most prevalent organochlorine compounds in precipitation, air and ocean waters in the northern hemisphere (Tanabe et al., 1982a; Oehme and Mano, 1984) thus their presence in arctic marine fishes is not surprising. Higher levels in some locations may reflect loading via riverine input in comparison with background contamination from ocean currents (Norstrom et al., 1985). Both HCH and toxaphene have low Henry's constants (10^{-7} atm m^3/mol) and are likely to undergo greater washout from the atmosphere and less volatilization from water or surfaces on which they are deposited than DDT, chlordane or PCB isomers (Eisenreich et al., 1981; Rapaport and Eisenreich, 1986). Thus contributions from surface runoff of HCH and toxaphene deposited by precipitation and dry deposition may be important in arctic marine waters with major freshwater inputs. To substantiate this hypothesis would require intensive sampling of both water and biota over a wide geographical area.

Apart from high p,p'- and o,p'-DDT in Arctic cod sampled at Pangnirtung no obvious geographical trends in s-DDT were evident within the limited sample size available. Total DDT in Arctic cod muscle was about 100-fold lower than that found in Atlantic cod liver off Halifax (Freeman et al., 1984) and is five to 10-fold higher than reported for Antarctic pelagic fish (Subramanian et al., 1983). Ratios of p,p'-DDE to total DDT in Arctic and Greenland cod muscle (Table 12A) were generally similar to those found by Sims et al. (1977) in East coast pelagic fish suggesting similar capability to degrade the DDT parent compound.

Dominant PCB isomers were tetrachloros 52, 66 and 70, pentachloros 95 and 118 and hexachloros 153 and 138. Similar patterns of PCB isomer accumulation in fishes have been noted in other field surveys (Duinker and Hillebrand, 1983; Tanabe et al., 1984) and in laboratory studies on accumulation of PCB formulations from water by fish (Tanabe et al., 1982b). The percent of each PCB homolog varied considerably between species and location (Table 12). This variation may reflect differences in lipid content and size of fish as has been noted in Antarctic marine fish (Subramanian et al., 1983). Broad whitefish, the oldest fish analysed with an average age of 13+ years, had amongst the highest percent heptachloro- isomers in comparison with Pacific herring (avg. age 5 yr) which is consistent with the trend to higher chlorinated homologs in older animals (Muir et al., 1986). Larger sample sizes would be necessary to confirm this observation.

Polyaromatic hydrocarbons. The results of the present study combined with those from Enviro-Test (1984) suggest that naphthalene and its derivatives are readily detected in arctic marine fishes. Enviro-Test (1984) determined naphthalene and phenanthrene derivatives by GC-MS in fishes from the Tuktoyaktuk region. They reported mono-, di- and trimethyl- naphthalenes in Tuktoyaktuk flounder and whitefish at similar levels as naphthalene (Table 15).

Enviro-test (1984) also reported phenanthrene and its methyl derivative were the major low molecular weight PAH in arctic fishes with concentrations ranging from <5 to 40 ng/g in Least cisco and Arctic flounder from Tuktoyaktuk and from <5 to 26 ng/g in Liverpool Bay Pacific herring. Wong et al., (1976) reported phenanthrene in Arctic and Least cisco collected in the southern Beaufort Sea at concentrations ranging from 4 to 15 ng/g. These levels are comparable or higher than those found in Arctic cod and far higher than in inconnu muscle (Table 14).

Pyrene and chrysene/benz(a)anthracene were previously detected in cisco from the southern Beaufort Sea at levels ranging from 1 to 10 ng/g (Wong et al., 1976). Lawrence and Weber (1984) reported the determination of fluoranthene and pyrene in Canadian commercial fish and found levels in the 1 to 2 ng/g range in various Lake Ontario species and sub-ng/g levels in Atlantic haddock. Smoked fish products generally contained fluoranthene and pyrene levels similar or higher than those reported here.

Benz(a)pyrene was undetectable by HPLC-FD (<0.1 ng/g) or GC-MS-SIM (<0.05 ng/g) in the limited number of samples analysed in this study. No benz(a)pyrene results from Canadian arctic fishes are available for comparison. Wong et al., (1976) citing unpublished data reported 15 ng/g in a single cod sample from Greenland and 18-55 ng/g in Greenland mussels. Sub ng/g levels of benz(a) pyrene have generally been found in Canadian commercial fishes and shell fishes (Dunn and Fee, 1979; Lawrence and Weber, 1984). Carp and pike from Hamilton harbour and the Detroit River contained variable but low (<0.01 - 0.2 ng/g) of benz(a)pyrene (Hallett and Brecher, 1984).

To summarize the PAH results, it appears that the levels found in the present study are lower than or comparable to results from surveys of marine fish by Wong et al., (1976) and Enviro-Test (1984) in the Southern Beaufort Sea area and are also similar to levels reported in commercial Canadian freshwater fishes.

Mixed-function oxidases. The published literature on MFO enzymes is inconsistent on the nature of the storage procedures required to preserve enzyme activity between times of sample collection and analysis. For example, Forlin and Andersson (1985) reported large losses in several MFO activities from Rainbow trout livers frozen on dry ice for as little as one day. In contrast with this, Spies et al., (1982) reported storage at dry ice temperature for several months without serious loss in activity. The possibility of loss of activity during storage has prompted some authors to transport live fish back to the laboratory so that the problem can be avoided. With Arctic fish the only currently practical means of sampling requires some form of sample storage and transport, and we have made a preliminary comparison of two methods of sample handling. In some fish the livers were dissected and frozen on dry ice within minutes of removal from the water; in others the whole fish was frozen in a household freezer and the liver was removed after shipment to Winnipeg.

We know of no comparable data either from these species at other locations or from other species in the Beaufort sea region, and consequently it is difficult to interpret these data as they stand. Many other reports of MFO activity can be found in the published literature, but they are complicated by the use of differing analytical methods and differing assay units to report activities. For example, some authors express activity in terms of weight of liver, or in terms of protein in the post-mitochondrial

supernatant, or in terms of protein in the microsomes. These and other differences make comparison among different sets of results difficult, but we have tabulated a sample of published results in Table 17, after conversion (approximately) from published activity units to the same ones we have used. In general, the fishes from Tuktoyaktuk harbour had higher activity than fishes from most published studies unless those studies included fish known or suspected to have been induced. A more firm conclusion regarding the status of the Tuktoyaktuk fishes will have to await the analysis of further samples of the same species from other locations.

CONCLUSIONS

Arctic marine fishes contain levels of heavy metals, polyaromatic hydrocarbons and organochlorines which are similar to or lower than levels in marine and freshwater fishes from southern Canada. Exceptions to this are high Cd in livers of Arctic cod from Pangnirtung and in Fourhorn sculpin and Pacific herring livers from Tuktoyaktuk as well as high toxaphene and HCH in Pacific herring and Arctic cod muscle. PAH levels in fish were similar to those reported in freshwater and marine fishes from relatively uncontaminated areas in southern Canada but lower than levels reported for heavily polluted areas. Further work should be conducted to better define geographic trends and within species variation in levels of contaminants. The number of individuals and size of most of the fish collected in this study was too small to adequately assess geographic and within species variation. This was in part deliberate because our main objective was to analyse a wide variety of contaminants over a wide geographical area but also illustrates the logistical problems in obtaining marine biota from arctic waters. Levels of organic contaminants were sufficiently low that samples had to be pooled to obtain reasonable analytical sensitivity. Mixed-function oxidase enzyme activities were obtained for some fish from Tuktoyaktuk harbour, and results were relatively high, although final interpretation of the results will have to await analyses of future samples.

The results represent an initial step in defining levels of contaminants and MFO enzymes in arctic marine fishes - something that has not been attempted previously except in the Beaufort Sea area.

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Table 1A. Trace metals in liver of Arctic cod (µg/g, wet wt).

Location	Field No.	Age	Cu	Cd	Zn	Hg	Se
Arctic Bay	1-8	4-6	-- [1]	--	--	--	0.62-0.98
Kugmallit Bay	1-15 [2]	2-3	--	--	--	--	0.24-0.78
Resolute Bay	4-5	2-3	--	--	--	--	0.30-0.86
Pangnirtung	1	11+[3]	<2.50	1.40	28.16	0.03	0.85
	4	12	<2.50	1.23	24.28	0.01	0.56
	9	--	<2.50	0.51	26.12	0.01	0.70
	12	--	<2.50	<0.50	20.37	0.01	0.51
	16	--	<2.50	0.50	24.86	0.01	0.78
	20	--	--	--	--	0.01	0.30

1 dashes indicate that too little sample was available for analysis.
2 6 fish, numbers 1,2,3,6,11,15.
3 age uncertain.

Table 2A. Trace metals in muscle of Arctic cod (µg/g, wet wt).

Location	Field No.	Age	Cu	Cd	Zn	Hg	Se
Arctic Bay	1	4 [1]	1.46	<0.05	10.59	0.02	0.40
	2	5	-- [2]	--	--	0.02	0.21
	3	4 [1]	1.21	<0.05	9.64	0.02	0.41
	4	4	--	--	--	0.02	0.54
	5	6	1.02	0.07	8.98	0.02	0.72
	6	6	1.74	0.07	16.97	0.03	0.56
	7	6	0.15	0.05	7.20	0.02	0.81
	8	5	0.07	<0.05	14.20	0.02	0.44
Kugmallit Bay	1	2+	--	--	--	0.02	0.43
	2	3	0.12	<0.05	9.42	0.02	0.51
	3	3	1.23	<0.05	7.94	0.01	0.44
	6	2	--	--	--	0.02	0.37
	11	3+	1.70	<0.05	12.76	0.02	0.44
	15	3[1]	1.18	0.05	1.44	0.01	0.33
Cambridge Bay	3	--	0.60	<0.05	7.26	0.02	0.33
Resolute Bay	4	3	--	--	--	0.05	0.42
	5	2	1.43	<0.05	10.71	0.02	0.43
Pangnirtung	1	11+ [1]	1.50	<0.50	26.37	0.05	0.33
	4	12	0.70	0.06	26.28	0.03	0.44
	9	--	0.05	<0.05	18.59	0.03	0.29
	12	--	1.53	<0.05	28.16	0.02	0.40
	16	--	0.90	<0.05	18.20	0.03	0.46
	20	--	0.84	<0.05	14.16	0.04	0.20

[1] age uncertain
[2] dashes indicate that too little sample was available for analysis.

Table 3A. Trace metals in kidney of Arctic cod (µg/g, wet wt)

Location	Field No.	Age	Cu	Cd	Zn	Hg	Se[1]
Arctic Bay	1-8[3]	4-6	--[2]	--	--	--	0.05-1.28[1]
Kugmallit Bay	2-15[4]	3	--	--	--	--	0.32-0.85[1]
Cambridge Bay	3	--	--	--	--	--	1.20[1]
Pangnirtung	1	11+[6]	--	--	--	--	0.72
	4	12	--	--	--	0.05	0.56
	9-20[5]	--	--	--	--	--	0.77-1.15

[1] weight available for analysis was less than 0.1 g; therefore determinations are somewhat uncertain.
[2] dashes indicate that too little sample was available for analysis.
[3] 7 fish, number 6 excluded.
[4] 4 fish, numbers 2,3,11,15.
[5] 4 fish, numbers 9,12,16,20.
[6] age uncertain.

Table 4A. Trace metals in gonads of Arctic cod (µg/g, wet wt).

Location	Field No.	Age	Cu	Cd	Zn	Hg	Se
Arctic Bay	1-8[1]	4-5	-- [2]	--	--	--	<0.70 [3]
Cambridge Bay	3	--	--	--	--	--	0.73
Resolute Bay	4-5	2-3	--	--	--	--	0.77-0.83 [3]
Pangnirtung	1	11+ [4]	0.39	0.22	37.15	0.02	0.57
	4	12	1.37	0.43	30.10	0.02	0.63
	9	--	--	--	--	0.02	1.08
	12	--	--	--	--	--	0.44
	16	--	--	--	--	0.05 [3]	0.70
	20	--	--	--	--	0.02	0.27

[1] = 3 fish, numbers 1,3,8
[2] = dashes indicate that too little sample was available for analysis.
[3] = weight available for analysis was less than 0.1 g, therefore determinations are somewhat uncertain.
[4] = age uncertain.

Table 5A. Trace metals in tissues of Broad whitefish, Pacific herring and Arctic flounder from Tuktoyaktuk Harbour (µg/g, wet wt).

Tissue	Field No.	Age	Cu	Cd	Zn	Hg	Se
1. Broad whitefish							
liver	37	13+	28.39	<0.50	40.30	0.08	0.68
muscle	9	--	0.25	<0.05	13.70	0.01	0.52
	37	13+	0.70	<0.05	15.09	0.03	0.25
kidney	9	--	1.02	0.13	48.66	0.05	1.92
	37	13+	0.49	0.04	44.96	0.06	0.49
gonads	9	--	1.67	0.14	101.65	0.02	1.35
	37	13+	3.60	0.12	29.29	0.04	0.44
2. Pacific herring							
liver	26	--	5.34	0.86	30.61	0.07	3.90
	27	5	--[1]	--	--	0.03	2.63
muscle	26	--	1.01	<0.05	7.33	0.02	0.55
	27	5	0.85	<0.05	6.65	0.02	0.46
kidney	26	--	--	--	--	--	2.94
	27	5	--	--	--	--	2.95
gonads	26	--	1.23	0.04	13.01	0.01	0.72
	27	5	1.81	0.04	30.89	0.01	2.26
3. Arctic flounder							
liver	70	6	5.04	<0.50	37.20	0.03	1.36
	71	6	--	--	--	0.03	1.85
muscle	70	6	0.32	<0.05	19.20	0.02	0.51
	71	6	0.60	<0.05	13.50	0.04	0.46
kidney	70	6	--	--	--	--	1.00
	71	6	--	--	--	--	1.05
gonads	70	6	0.53	0.07	84.45	0.03	0.76
	71	6	0.37	0.03	15.37	0.02	0.44

[1] dashes indicate that too little sample available for analysis.

Table 6A. Trace metals in tissues of Greenland Cod from Cambridge Bay (µg/g, wet wt).

Tissue	Field No.	Age	Cu	Cd	Zn	Hg	Se
liver	1	--	14.09	<0.50	28.80	0.03	0.97
	2	--	13.64	<0.50	32.42	0.07	1.16
	4	--	21.34	<0.50	31.60	0.04	1.12
	5	--	12.86	<0.50	24.72	0.03	0.88
	6	--	28.71	<0.50	28.83	0.05	1.25
	7	--	4.99	<0.05	22.22	0.03	1.47
muscle	1	--	0.52	<0.05	4.04	0.05	0.37
	2	--	0.41	<0.05	4.91	0.03	0.33
	3	--	0.60	<0.05	7.26	0.02	0.33
	4	--	0.30	<0.05	3.26	0.05	0.24
	5	--	0.25	<0.05	4.62	0.03	0.37
	6	--	0.23	<0.05	4.90	0.05	0.33
	7	--	0.81	<0.05	17.10	0.05	0.37
kidney	1-6	--	-- [1]	--	--	--	0.95-1.20
	7	--	--	--	--	0.17	1.05
gonads	1	--	0.45	0.04	55.77	0.02	0.77
	2	--	0.69	0.04	85.82	0.02	1.26
	3	--	--	--	--	--	0.73
	4	--	0.52	<0.02	60.02	0.02	0.94
	5	--	0.37	0.02	55.57	0.01	0.92
	6	--	0.40	0.03	84.89	0.02	0.88
	7	--	0.38	0.02	18.31	0.02	0.65

[1] dashes indicate too little sample was available for analysis.

Table 7A. Trace metals in tissues of Fish doctor from Resolute Bay (µg/g, wet wt).

Tissue	Field No.	Age	Cu	Cd	Zn	Hg	Se
liver	2	13+	--[1]	--	--	--	0.33 [2]
	3	12+	--	--	--	0.06	0.85
muscle	2	13+	0.80	<0.05	12.16	0.07	0.34
	3	12+	0.59	<0.05	14.42	0.08	0.23
kidney	2	13+	--	--	--	--	0.51 [2]
	3	12+	--	--	--	--	0.59 [2]
gonads	2	13+	--	--	--	--	0.17 [2]
	3	12+	--	--	--	--	0.35 [2]

1 dashes indicate that too little sample was available for analysis.
2 weight available for analysis was less than 0.1 g, therefore determinations are somewhat uncertain.

Table 8A. Trace metals in tissues of Fourhorn sculpin from Resolute Bay (RB) and Tuktoyaktuk (T) (µg/g, wet wt).

Tissue	Field No.	Area	Age	Cu	Cd	Zn	Hg	Se
liver	1	RB	--	-- [1]	--	--	--	0.15
	65	T	8+	2.44	0.57	41.09	0.14	0.99
	67	T	13+	4.15	0.54	39.09	0.23	1.23
muscle	1	RB	--	--	--	--	0.05	0.25
	65	T	8+	0.99	0.05	19.81	0.20	0.36
	67	T	13+	0.90	<0.05	21.46	0.16	0.37
kidney	1	RB	--	--	--	--	--	0.56 [2]
	65	T	8+	--	--	--	--	0.85
gonads	65	T	8+	0.49	0.05	19.38	0.14	1.41
	67	T	13+	0.56	0.07	26.97	0.03	1.48

[1] dashes indicate too little sample was available for analysis.
[2] weight available for analysis was less than 0.1g, therefore determinations are somewhat uncertain.

Table 9A. Chlordane, HCH and chlorobenzene isomers in arctic marine fishes (ng/g wet wt) 1984.

Location	sample	No.	a-HCH	g-HCH	HCB	trans-chlordane	cis-chlordane	oxychlor-dane	cis-nonachlor	trans-nonachlor	U3[1]	hept-epoxide	s-HCH	s-chlor-dane
Arctic Bay	A. cod	1	17.54	0.58	1.18	<0.05[2]	0.62	0.16	0.07	0.62	0.19	0.31	18.1	1.97
	A. cod	2	11.24	0.68	1.00	<0.10[3]	0.54	0.15	<0.10	0.42	<0.10	0.24	11.9	1.35
Resolute	A. cod	1	1.84	0.17	2.46	<0.05	0.67	0.35	0.22	1.20	0.47	0.16	2.0	3.07
Pangnirtung	A.cod	1	5.64	0.44	1.00	0.69	1.49	0.37	0.45	0.95	0.15	<0.05	6.1	3.41
Tuktoyaktuk	whitefish	1	0.03	<0.05	0.09	0.05	0.17	<0.05	0.05	0.21	0.05	<0.05	0.03	0.48
	P.herring	3	11.85	0.61	0.62	<0.05	1.60	0.89	0.48	1.73	0.70	0.20	12.46	5.60
	A.flounder	4	0.17	<0.05	0.13	0.04	0.07	<0.05	<0.05	0.30	0.10	<0.05	0.17	0.51
	inconnu	5	0.15	<0.05	0.40	0.18	0.66	0.29	0.28	1.33	0.40	0.11	0.15	3.25
Cambridge Bay	G. cod	1	1.06	0.15	0.32	0.09	0.37	0.12	0.13	0.28	<0.12	<0.05	1.21	1.11
	G. cod	2	0.23	<0.05	0.29	<0.05	0.37	0.20	0.27	0.17	<0.30	<0.05	0.23	1.31
Frobisher	G. cod	1	0.24	0.06	0.94	<0.05	0.19	0.11	0.23	0.09	0.04	<0.05	0.30	0.66
	G. cod	2	0.40	0.09	0.69	<0.05	0.30	0.18	0.26	0.11	0.32	<0.05	0.49	1.17

[1] - t-nonachlor isomer in Fraction 1.
[2] - detection limit for HCH and chlordane isomers in 50g wet wt samples.
[3] - detection limit for chlordane isomers with an 8g sample.

Table 10A. DDT isomers, dieldrin and PCBs in arctic marine fishes (ng/g wet wt) 1984.

Location	Sample	No.	p,p'-DDE	p,p'DDD	p,p-DDT	o,p'-DDT	dieldrin	s-DDT[1]	s-PCB[2]	s-chlordane / s-PCB	DDE / s-DDT	s-DDT / s-PCB	Arochlor[3] 1:1	Arochlor[4] 1260	toxa-phene
Arctic Bay	A. cod	1	0.40	0.30	0.94	0.28	1.41	1.92	1.84	1.07	0.42	1.04	1.88	0.58	23.
	A. cod	2	0.21	<0.20[5]	0.45	<0.20	1.08	0.66	<1.0[6]	>1	≈1.0	-	<1.0	<1.0	<2
Resolute	A. cod	1	1.25	0.22	0.66	0.30	0.77	2.43	3.69	0.83	0.51	0.66	7.23	1.88	14.
Pangnirtung	A. cod	1	0.72	1.15	4.14	0.33	0.45	6.34	4.49	0.76	0.11	1.41	5.33	1.27	46.
Tuktoyaktuk	whitefish	1	0.23	0.09	0.09	<0.05	<0.05	0.41	1.83	0.26	0.56	0.22	2.97	0.59	<2
	herring	3	0.17	<0.05	4.51	0.30	0.63	4.98	4.20	1.33	0.29	1.19	2.55	0.81	74.
	flounder	4	0.56	0.22	0.31	<0.05	<0.05	1.09	4.67	0.11	0.51	0.23	6.79	2.27	<2
	inconnu	5	0.68	0.40	1.37	<0.05	0.37	2.45	3.11	1.05	0.79	0.79	3.62	1.02	24.
CambridgeBay	G. cod	1	0.82	<0.05	0.96	0.05	0.15	1.83	3.53	0.31	0.45	0.52	5.22	1.48	<2
	G. cod	2	0.72	<0.05	1.27	0.19	<0.05	2.18	2.97	0.44	0.33	0.73	4.86	1.25	<2
Frobisher	G. cod	1	1.22	<0.05	1.48	0.11	<0.05	2.75	2.30	0.29	0.44	1.20	4.17	0.88	6.
	G. cod	2	0.96	<0.05	0.80	0.33	0.14	2.09	4.13	0.28	0.46	0.51	5.10	1.27	<2

1 - Sum of DDT isomers.
2 - Sum of individual PCB isomers (Table 13A) except trichlorobiphenyls.
3 - Isomer 138 expressed as Arochlor equivalent.
4 - Isomer 180 expressed as Arochlor equivalent.
5 - detection limit <0.20 ng/g for this sample (8g wet wt)
and <0.05 ng/g for other samples (50g wet wt).
6 - detection limit 1.0 ng/g for PCBs and 2 ng/g for toxaphene with 50g sample.

Table 11A. Individual PCB isomers quantitated by HR-GC-ECD in arctic marine fishes (ng/g wet wt) 1984.

Location	Sample	No.	#52	#49	#70[1]	#95/66[2]	#99	#101	#110	#118	#149	#146	#153	#138	#187	#183	#180	#170
Arctic Bay	A. cod	1+2	0.23	<0.10[3]	0.14	0.18	0.11	0.15	0.16	0.16	0.12	0.08	0.19	0.14	0.08	<0.02[4]	0.10	<0.02
Resolute	A. cod	1	0.12	<0.10	0.07	0.21	0.28	0.18	0.20	0.27	0.09	0.14	0.86	0.71	0.06	0.07	0.32	0.11
Pangnirtung	A. cod	1	0.46	0.23	0.26	0.48	0.09	0.38	0.24	0.36	0.51	0.12	0.37	0.42	0.21	0.11	0.17	0.08
Tuktoyaktuk	whitefish	1	0.15	<0.10	0.09	0.17	0.08	0.18	0.10	0.16	0.18	<0.05[5]	0.23	0.23	0.11	0.07	0.08	<0.02
	herring	3	0.46	0.16	0.28	0.58	0.41	0.28	0.32	0.15	0.71	<0.05	0.25	0.20	0.11	0.18	0.11	<0.02
	flounder	4	0.37	0.15	0.19	0.32	0.19	0.36	0.28	0.37	0.39	0.07	0.56	0.54	0.29	0.16	0.30	0.13
	inconnu	5	0.21	<0.10	0.14	0.24	0.31	0.29	0.29	0.29	0.47	0.07	0.38	0.29	0.15	0.09	0.14	0.04
CambridgeBay	G. cod	1	0.34	<0.10	0.20	0.35	0.12	0.33	0.19	0.18	0.32	0.09	0.40	0.41	0.20	0.12	0.20	0.08
	G. cod	2	0.33	<0.10	0.04	<0.10	0.22	0.23	0.12	0.37	0.21	0.13	0.55	0.38	0.07	0.07	0.17	0.08
Frobisher	G. cod	1	0.06	<0.10	0.08	0.14	0.17	0.17	0.21	0.34	0.19	0.08	0.29	0.33	0.07	<0.02	0.12	0.05
	G. cod	2	0.41	<0.10	0.16	0.28	0.27	0.39	0.31	0.39	0.52	0.14	0.53	0.40	0.02	0.09	0.17	0.05

[1] - Quantitated using response factor estimated from percent. of #70 in Arochlor 1254 total for chromatogram.
[2] - Average response factor for 95/66 peak estimated from Arochlor 1254 total for chromatogram.
[3] - Detection limit = 0.10 ng/g for Cl_4 on a 50g sample extract/mL.
[4] - Detection limit = 0.02 ng/g for Cl_7 on a 50g sample extract/mL.
[5] - Detection limit = 0.05 ng/g for Cl_6 on a 50g sample extract/mL.

Table 12A. Additional tri- and tetra-chlorobiphenyls in Arctic cod muscle (ng/g wet wt) quantitated by SIM [1].

Location	No.	31	28	21	47	44	66[2]	74	95[2]	56/60	84/89
Arctic Bay	1+2	0.17	0.13	0.09	0.05	0.08	0.10	0.05	0.14	0.06	0.04
Resolute Bay	1	0.06	0.05	0.01	0.11	0.04	0.06	0.07	0.18	0.03	0.02

[1] Quantitated using SIM peak areas and average response factors for tetra- and pentachlorobiphenyl standards under SIM conditions.

[2] 66 and 95 are actual SIM peaks rather than combined peaks quantitated by an average response factor with the electron-capture detector (Table 13A).

Table 13A. Structures of numbered PCB isomers detected in marine fish muscle.

IUPAC Number	Structure
21	2,3,4-trichlorobiphenyl
28	2,4,4'-
31	2,5,4'-
44	2,3,2',5'-tetrachlorobiphenyl
47	2,4,2',4'-
49	2,4,6,2'-
52	2,5,2',5'-
56/60	2,3,5,3'-/2,3,4,4'-
66	2,3,3',4'-
70	2,5,3',4'-
74	2,4,5,4'-
84/89	2,3,6,2',3'-/2,3,4,2',6'-pentachlorobiphenyl
95	2,3,6,2',5'-
99	2,4,5,2',4'-
101	2,4,5,2',5'-
105	2,3,4,3',4'-
110	2,3,6,3',4'-
118	2,4,3',4',5'-
138	2,3,4,2',4',5'-
146	2,3,5,2',4',5'-
149	2,3,6,2',4',5'-
153	2,4,5,2',4',5'-
170	2,3,4,5,2',3',4'-heptachlorobiphenyl
180	2,3,4,5,2',4',5'-
183	2,3,4,6,2',4',5'-
187	2,3,5,6,2',4',5'-

Table 14A. Characteristic ions of PAHs monitored by GC-MS SIM.

Compound	Characteristic ions (m/z)	Retention time window (min)
Naphthalene	127, 128, 129	7 - 13
naphthalene-d8[1]	136, 68	7 - 13
Methyl naphthalene	142, 141	7 - 13
Dimethyl naphthalene	155, 156	7 - 13
acenaphthylene	151, 152, 153	7 - 13
fluorene	165, 166, 167	13 - 18
phenanthrene/anthracene	176, 178, 179	13 - 18
methylphenanthrene	192, 193	13 - 18
dimethylphenanthrene	206, 204	13 - 18
anthracene-d10[1]	188, 94, 80	13 - 18
fluoranthene/pyrene	100, 101, 202	18 - 20
chrysene-d12[1]	120, 236	20 - 26
benzo(a)anthracene/chrysene	226, 228, 229	20 - 26
benzo(a)pyrene	125, 252, 253	20 - 26
benzo(a)pyrene-d12[1]	262, 264	20 - 26

[1] deuterated standard.